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SOARING FLIGHT.*

BY

WOLFGANG KLEMPERER.

I CONSIDER it a very great privilege to have been asked to speak to you within these venerable walls which have witnessed the infancy of many a discovery that later became a milestone of the progress of civilization. Flying is one of them. It was the dream of man for several thousand years. To this generation this dream came true by the most remarkable development of aviation, in which American genius played an important rôle. Man now can fly, higher than the highest mountain, faster than the swiftest bird or cloud; the power of thousands of horses can be concentrated in an engine occupying but a few cubic feet capable of lifting many tons of freight into the air. On the other hand, we have also learned to soar in the air for hours without any motor at all.

Many people wonder how this is done, whereas the motor-driven airplane is quite familiar to them. Strange that it is not the other way around. For the great soarers among the birds, the albatross and seagull, the eagle, buzzard, hawk and vulture, are masters of the art of flying without any expenditure of motive power. They display it before our very eyes, sailing without flapping their wings for hours at times. Had their secrets been understood earlier, they could have taught man to fly long before any motor was invented.

In fact, the pioneers of aviation, such as Lilienthal and the

* Presented at a meeting held Thursday, February 10, 1927.

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FIG. 1.

Above the Rhön country.

Wright brothers, started on this track. It was by coasting down from hills in their early motorless gliders that they acquired the first real flying experience necessary to understand the basic mechanics of flight. Had not the automobile engine happened to be developed just at that time, the history of flying might have assumed a perfectly different aspect. But thus, the rapid success of the motor-driven airplane seemed to render further gliding experiments unnecessary and it was not earnestly resumed until after the World War, which had brought a tremendous impulse to flying. This impulse had resulted in spectacular improvements of design and engineering, in a marvellous perfection of piloting and performance and, simultaneously, in giving scientists a chance and stimulation to advance theoretical and systematic empirical knowledge to a very satisfactory degree.

When gliding was resumed in Germany in 1920, it was done with the intention of applying this accumulated technical knowledge to the original problem of duplicating the soaring flight of birds. A meeting reunited those interested in the idea and organized the first experimental gliding contest. A camp was pitched near the top of Mount Wasserkuppe in the Rhön Mountain district. This mountain rises about 2000 feet above the plain to its north, surrounded by smaller hills. Its slopes offer all topographical varieties from gentle grassy grades bare of trees, to rugged gorges and fir-covered hollows. Initial success was modest but we soon learned to make prolonged glides and we saw we were on a promising track. In the following year, gliding developed into soaring. A series of duration flights increasing from five up to twenty minutes, some of them covering distances of a few miles; the first so-called cross-country flights without a motor aroused nation-wide interest.

A society for the promotion of soaring flight was organized and now the Rhön Mountains have become a classic stadium of the air where annual meetings and contests are held. Glider schools and, recently, an elaborate permanent research institute were established there. Our primitive tents were gradually replaced by more permanent buildings, auto roads were built. No more the flyers themselves have to carry their own food and tools uphill in a two-hour hike from the nearest little town, sometimes getting lost in the heavy fogs or clouds which only too often justified the wet name of that mountain.

The year 1922 brought a spectacular progress. It was due to favorable weather conditions during the three weeks of the meeting and to the lessons learned by designers and pilots in the preceding contests. The slopes of the Wasserkuppe, which formerly had not even been known to many, were crowded with thousands of spectators who were thrilled watching the human birds for hours soaring above their heads, three and four at a time.

The absence of any motor and its noise, together with the slow speed of the glider flying against the wind, enables the pilot above and the crowd below to carry on oral conversation, and to furnish the flyer with meteorological information. Great emotion prevailed when the first one-hour mark was reached. The pilot, cruising at some distance from the peak, would every once in a while return to near the starting-point and the watching crowd and inquire about how long he had been up in the air. When he had climbed too high for the voice to be intelligible, then scores of spectators would be grouped to form huge live numerals on the ground indicating the number of minutes flown.

Since then, soaring has been taken up in various other countries as well, especially in England, in France (on the coast of the English Channel), in the Alps of Switzerland, Italy and Austria, in the hills of northern Czechoslovakia, on the North African coast of the Mediterranean and in the Crimea range of southern Russia. In Germany, Rossitten on the East Prussian coast of the Baltic Sea became another centre of soaring flight sport and research. Not to mention all the scattered hills where local glider clubs have taken up training for the bigger national annual events.

In spite of all this surprising development, soaring flight has not so far revolutionized the aspects of commercial or military aviation nor could anybody earnestly expect it to do that. The main reason is: Soaring depends primarily upon the wind exactly as a sailing vessel on the water does. Then, many people will ask: What is it good for? This would be a question similar to: What is yachting good for in the age of ocean liners? There are three purposes for which soaring flight is pursued.

First of all, it is an unrivalled sport. I am unable to describe by words the sublime pleasure one experiences in gliding over hills and valleys, silently, like the eagle, cruising or hovering, rising or descending at will. The ample controllability makes you feel like them, master of the air. The constant alertness watching for

favorable air-currents and studying their relations to the varied scenery below provides thrill and challenge. A few weeks in a glider camp is outdoor life in the word's fullest meaning. Soaring flight requires also a certain amount of scientific training, engineering sense and physical skill. Thus it most perfectly blends all the elements requisite for a recreational and educational sport such as the rising generation so appreciates.

Aside from this pedagogical value, the scientific research

FIG. 2.

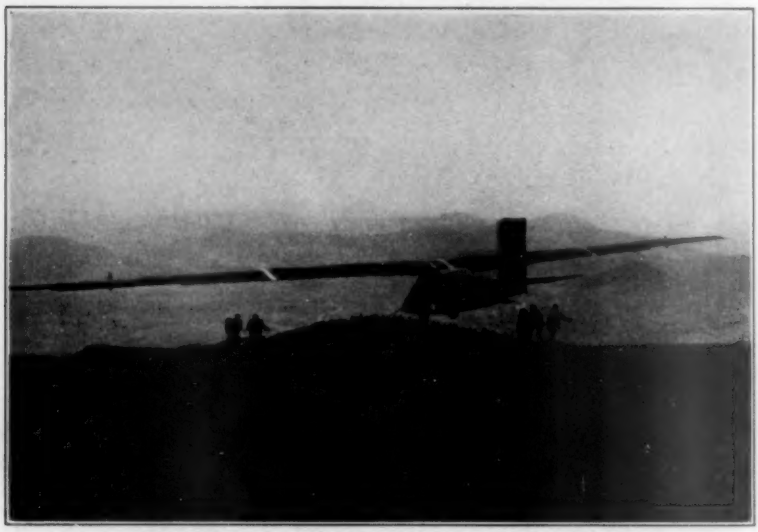
Waiting for wind.

laboratories, both those governmental and those connected with the aeronautic industry, discovered a treasure in gliding. The most difficult problem in aeronautical science is the proper correlation between theory and research experiments on one side and the complex phenomena of practical flight on the other. The application and verification in practice of the results of theoretical investigations is often just as difficult as the laboratory investigation of some acute practical problem. The aerodynamical conditions in the Wind Tunnel Laboratory where models are tested in an artificial air-stream are in many respects far from identical with those prevailing in actual flight. Gliding and soaring flight now offer supplementary experimental means, as a full-size flying laboratory, for investigating into such problems in which the

elimination of interference of a propeller slip stream with the lift of wings, stability and control is essential.

A third field wherein the glider is useful is in the abundance of opportunity it affords for acquiring aerial experience which is of unlimited value in the training of future commercial and private flyers. Glider champions as a rule afterwards became superior airplane pilots, whereas the reverse did not hold so generally, although, of course, many of the new pioneers of soar-

FIG. 3.



A take-off. Notice the enormous wing span. (Espenlaub.)

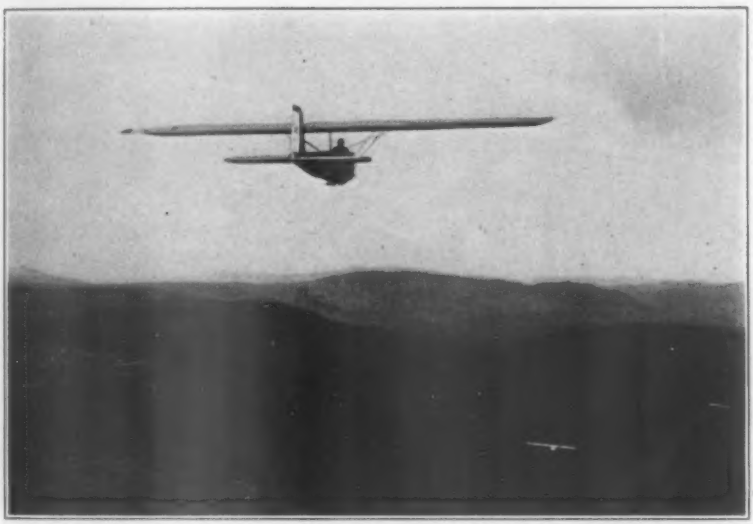
ing flight were much benefited by their previous extensive motor flying experience. No doubt, gliding constitutes an excellent means of initial aviatic training and has thereby already done a tremendous lot to make aviation popular and promote air-mindedness.

In fact, any motor flight is terminated by gliding down to land. Of course, the idea of soaring flight is to glide not down but level or even to gain altitude. Now let us see how this is done without a motor.

Theoretically, we may distinguish between "static" soaring flight and "dynamic" soaring flight, although in practice they may overlap or blend.

The principle of static soaring is trivially simple. It consists in gliding down in a rising current of air. Provided the vertical velocity component of the air-current exceeds the minimum rate of descent of the machine, any airplane can climb without a motor, at a rate of ascent equal to that excess. A wind blowing over a vast plain, suddenly confronted with a large mountain range extending across its path, would of course be deflected upwards. A wind blowing at say 32 ft./sec. up a slope 1 : 4

FIG. 4.



Spot landing contest. (E. Meyer.)

would furnish 8 ft./sec. lifting component. An airplane flying at 60 ft./sec. and having a gliding angle of 1 : 8, thus a natural rate of descent of 7½ ft./sec., would still be carried up at ½ ft./sec. and yet proceed at 28 ft./sec. against the wind. However, this would soon carry it too far upwind, out of the zone of vertical deflection. This is why the soaring birds and experienced glider pilots cruise weaving to and fro along the mountain ridges, always trying to keep within the zone of strongest lift.

Of course, the wind does not exactly follow the contour of the hillside in equidistant flow-lines. As far as the windward side of the wind-obstruction is concerned, model experiments in wind-tunnels have given interesting results and perspicuous flow pic-

tures can be derived by calculation, using the method of sources and sinks. A combination of sources and sinks is so chosen that the fictitious fluid produced by these sources and washed leewards by the flow representing the wind is completely housed within a shape that coincides with the contour of the mountain. Then, the direction and magnitude of the local velocity anywhere in the field can be calculated by simple geometrical addition of the

FIG. 5.

Elaborate internal trusswork of a glider wing.

horizontal wind to the resultant influence of all sources and sinks upon that point.

Since the equations of the stream-lines happen to be identical with the equations of the equipotential lines in an electric field, several investigators have made experimental use of this remarkable analogy and derived flow structures by electrically sounding in a tank filled with an electrolyte between electrodes shaped according to the boundary lines of the flow problem.

Actual full-size measurements of the wind texture on the windward side of the coast at the Rossitten soaring flight site were accomplished last summer by taking motion pictures of the clouds left by smoke rockets fired up to various heights. The results of these experiments and others made with ammonia clouds revealed that the acceleration of the wind right above the crest and the upward deflection at the bottom of the slope are

somewhat smaller than would be expected from the analogous potential flow. Explanation is anticipated to be found in friction and the thermic gradient.

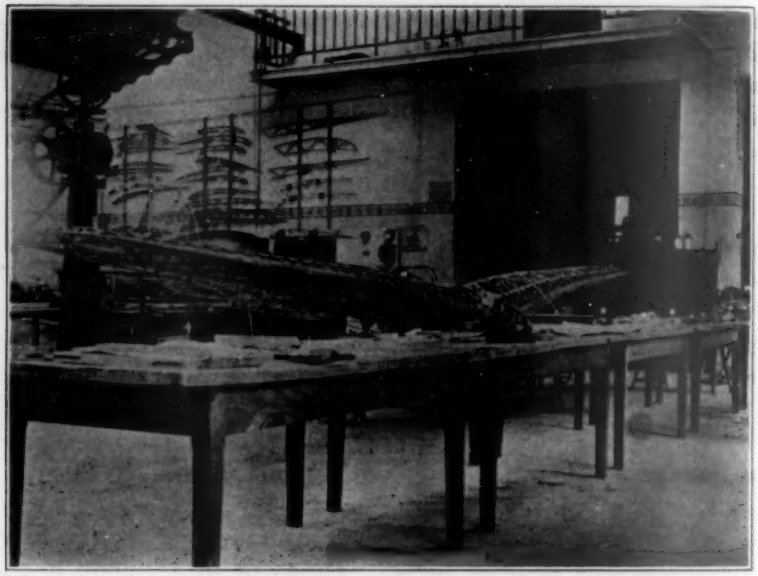
The best locations for static soaring are usually to be found at some distance windwards off the crest. The useful zone may extend to considerable altitude, at times twice as much as the height of the mountain above its base. Obviously, the vertical deflection component decreases with higher altitude. Thus a glider which has a well-defined minimum rate of descent will find a definite "ceiling" above the crest, beyond which he cannot climb in static soaring. Very favorable conditions occur above horseshoe-like formations of gorges. The leeward side of the mountain is feared for its treacherous descending currents, weird whirls and dead zones.

It is easy to see that there is no fundamental difficulty in remaining aloft for an unlimited duration as soon as the pilot has found a sufficiently wide area of sufficiently strong rising wind-currents, as long as he sticks to it and the wind endures. In fact, some of the duration record flights were made by patiently cruising in figure eights above the same place and extended far into night-time, when landings had to be made in the light of automobile headlights and flares. The longest duration ever flown by a glider was twelve hours and a few minutes, attained by Herr F. Schulz in 1924 on the Rossitten coast. The same pilot has later flown nine hours with a passenger.

It is considerably more difficult to cover large distances, however. The first distance flights were made by climbing to the "ceiling" and then taking a flat glide across or more or less with the wind. Later we learned to pick up altitude under way. At Rossitten, Herr A. Martens managed to sail all along the chain of coast dunes for some fifteen miles and back to his base. The plucky Darmstadt college glider team finally perfected the art of sailing from mountain chain to mountain chain across valleys and plains. A wonderful feat was the winning of the Milseburg prize by Herr Nehring, their youngest member. The task was to start from Mount Wasserkuppe, to fly to the Milseburg, an ancient rock castle some seven miles distant, to circle it and to return to the starting-point, without a motor, of course. After climbing some 500 ft. above the crest in a moderate wind blowing about

across the direction of his goal, he crossed the valleys and intermediate hills and arrived near the castle in good fashion. Due to other hills surrounding the Milseburg and impairing aerial conditions there, he lost a good deal of height. Thus it looked as though he would never be able to complete the return trip. However, by making clever detours to the windward slopes of various other hills he managed to gather enough lift again to negotiate the worst gaps and valleys and finally alighted only 400 ft. from

FIG. 6.



Glider under construction at Aachen College.

his starting-point. This flight strikingly demonstrated what tremendous possibilities long-distance soaring in hilly country presents.

Vertical currents are not entirely confined to mountainous regions. Every cumulus cloud is the top of one. The variations of solar radiation and of the thermal capacity of different varieties of soil cause the atmosphere to heat very irregularly. Above some localities hot air rises, above others cold air descends. In tropical regions such thermical drafts attain formidable velocities. In Guinea, Central Africa, the French scientist P. Idrac has measured vertical velocities ranging from 2 to 5 ft./sec. By means

of kites, he lifted wind-speed meters up into the strata where vultures were soaring at the time.

Airmen do not like to fly in clouds. However, they are visible indicators of the rise of saturated air. To glide not only from mountain to mountain, but also from cloud to cloud, was the ambitious goal the soaring flight pioneers had set out to attain.

During last year's Rhön meeting, the German pilot Herr M. Kegel was caught by a thunderstorm. Threatening clouds came rapidly rolling up towards the Wasserkuppe. Two other pilots who also were in the air, decided to land. Kegel, however, drove right up to the front of the monstrous roller and clung to it. Soon he was out of sight of the amazed spectators. He let himself be carried by the clouds' upwash as high as about 4000 ft., and thus actually travelled a distance of forty miles. Eventually, he headed leewards out of the region of the disturbance and beat the storm for a safe landing. The whole flight had lasted three-quarters of an hour. According to his own account, he must have had a thrilling time when he was bounced about by the violent cross-currents in that aerial whirlpool, visibility at times completely extinguished in the dense mass of turbulent foam. There is no doubt about Herr Kegel's ability as a pilot, but it may be mentioned that he had also built his machine himself in his spare time and it was one of outstanding efficiency and workmanship, too.

There is some advantage in flying in adverse weather. Quite a number of spectacular soaring flight events were indeed distinguished by rather unsettled weather conditions. The stormier, the greater the chances for reaching high altitudes. Gliders have often climbed 1000 ft. above the crest of the mountain. Since 1921 the gliders were out in any weather up to gales of 45 m.p.h. Only a dead calm would confine them to idle waiting. What a difference from the state of affairs during the early days of motor-driven aircraft. No airman will deny that learning how to buck gales immediately close to mountain ridges constitutes a very valuable training for meeting unexpected aerial situations.

In a flat country, even in the absence of meteorological disturbances, vertical currents may be induced, for instance, at the border-line of a smooth and a rough surface. Imagine the wind blowing over a great grassy plain or a great body of shallow water, then striking an adjacent forest, the trees of which obviously absorb more energy per unit of area. The friction

layer in which braking impulse is transmitted will here extend higher than above the smooth plain. The retarded air has no other escape but upward deflection. Ravens and buzzards can sometimes be seen soaring a short distance leewards of such border-lines of surface roughness.

When one only temporarily happens to find profitable upward currents, it is obviously best to concentrate production of lift during these favorable periods, by rising or by storing kinetic

FIG. 7.

A gull-like design. (Aachen.)

energy in order to gain some reserve to draw upon while negotiating the lull. In fact, the wind is almost never like a viscous stream. It contains turbulence and there is something like one-third of the chances for the occurrence of vertical turbulence components. Fortunately, the mere inertia causes any airplane to gain from such vertical pulsations a slight increase in lift or a slight reduction of drag. Katzmayer, in Vienna, proved this by model experiments in the wind-tunnel, introducing artificial cross-wind pulsations. The theoretical explanation of the phenomenon is this: Any upward fluctuation causes the relative air-stream to strike the wings at some inclination upwards, thereby inclining

the resultant air force forward. In the descending phase of the fluctuation the reverse holds, thus inclining it backwards. The pull of the first case and the additional drag in the second would eventually cancel out, if they were of equal magnitude. However, in the rising phase the angle of attack and, consequently, the lift are increased, in the descending phase it is decreased. Therefore the forward component wins. Lift is automatically concentrated during the period when power is transmitted from the air to the machine. The airplane combs the fluctuation. We often call this phenomenon the "Knoller-Betz" effect, after the names of two scientists who independently published the first explanations in 1912 and 1913. It may be that this is the same phenomenon which causes discrepancies between the results of wing-model tests conducted at various laboratories or under different conditions of turbulence.

Flying through vertically pulsating air, the operation of the elevator in a certain rhythm, would yield an optimum power gain a little in excess of that natural gain which would be derived from inertia alone. However, there is no conspicuous periodicity in the vertical wind fluctuations and it would be extremely difficult for the pilot to estimate their harmonic constituents and, above all, to discriminate in time between vertical and frontal gusts.

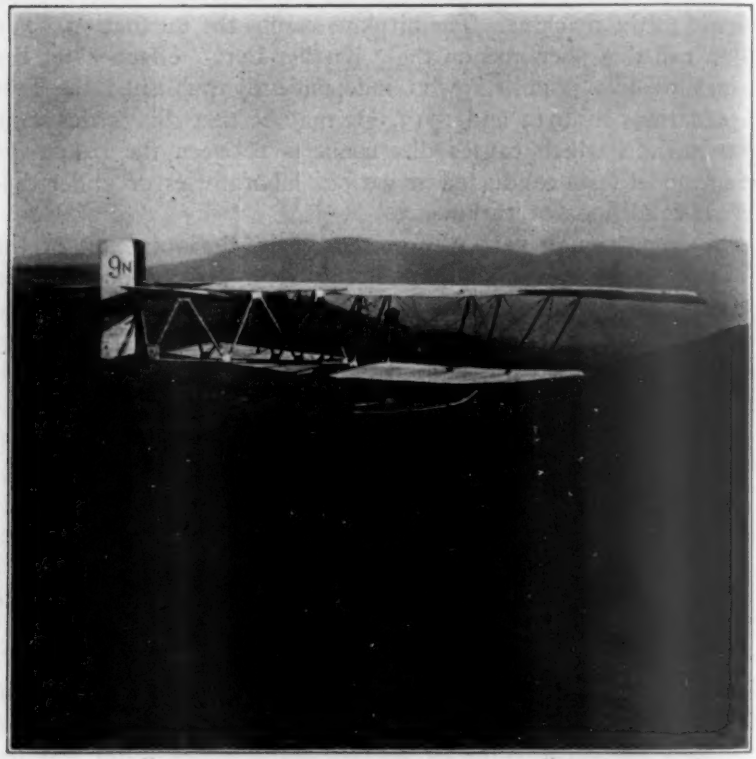
The utilization of the latter is a different proposition and leads us to dynamical soaring proper. It is obvious and well known that the horizontal mean velocity component of the wind cannot be captured from any free flying vehicle. It can be by a kite which is connected to the solid ground by a cord.

Soaring flight is in some languages called "Sailing Flight." The comparison with sailing does not lack some justification. The sailing vessel depends upon its simultaneous contact with two mediums, the sail with the air, and the keel with the water. Without the keel part it would be helpless. A round nut-shell without a keel would drift uncontrollably with the wind. So would a sailed ice-sled put on balls. Furthermore it is only the relative motion between these two mediums that can be utilized. When the wind blows with the same velocity and direction as the river flows, sails are dead and worthless to the river craft.

Now, where is the other medium to lean against from an aircraft totally surrounded by nothing but the wind. It can only

be portions of the wind which move at velocities different from the average. The wind is almost never uniform. In one place and at one instant it moves faster than at another. It is these irregularities from which, in dynamic soaring, energy is drawn. Conventional types of aircraft, contrary to naval craft, lacking the advantage of manœuvring at the contact surface of two media,

FIG. 8.



A training biplane glider.

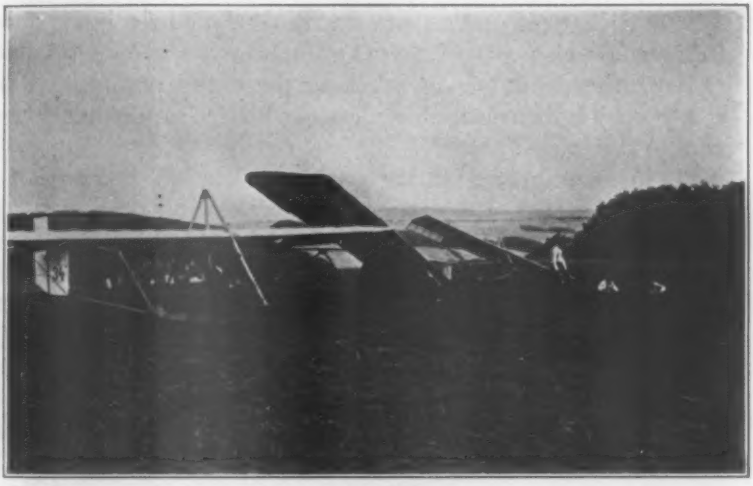
cannot get a hold of them simultaneously. Thus we have to merge into each of them alternatingly, relying on inertia as a substitute for the mast and rigging.

On a sailing boat, the angle of attack of the sail by the wind and that of the keel by the water lie towards opposite sides. The equivalent condition has to be brought about in dynamic soaring by facing the two portions of the wind in opposite directions.

This involves certain manœuvres which deserve some particular investigation.

Let us consider an idealized form of gustiness. Imagine the wind to fluctuate between the extremes of 20 and 60 m.p.h. Let the acceleration during the freshening period be constant, say 4 ft./sec.^{2}, or one-eighth of that of a dropped body. It would take 10 seconds between two extremes. Suppose we had been flying facing the slow 20-m.p.h. wind. Now the wind freshens

FIG. 9.



A fleet of training gliders.

up. If we should not react, we would gain excess speed against the air due to our own inertia. However, we do not want more speed, since our lift just balances our weight. Thus we decide to throttle down our motor, and assuming the drag of our machine to be one-eighth of its weight, we could just shut off that engine completely. Our drag would just retard us so much that our speed against the swelling gust will be constant, and we continue our level flight, without any propulsive power other than the reaction of inertia. However, this condition will last only 10 seconds. Upon reaching the climax of the gust, the negative acceleration of the calming-down period would have a retarding effect on us and we would need twice our normal engine horsepower in order to catch up with it. After completing the cycle

we would have gained nothing at all. However, the idea of this sort of dynamic soaring is: Not to wait until the lull spoils the temporary gain, but to turn away in the meantime. Then when the calming-down stroke arrives, one is headed already the other way and gets another free lift equal to the preceding one, since now he transports the impulse from the fast wind portion into the slow one.

This manipulation is by no means a mysterious case of perpetual motion. In fact, the airplane or bird so circling picks energy from that stored in those meteorological irregularities. Its action somewhat resembles that of a traffic cop on the road, slowing down fast elements of (wind) traffic and speeding up slow ones, with the result of smoothening the entire motion. If he does a good job there is nothing left for his fellow farther downstream to do.

It is interesting that not the actual accelerative structure of a gust is what counts, but the average acceleration only, between the times of change of course of the craft. If this is the same or more in proportion to gravity than the ratio of drag to lift of the airplane or bird, the soaring effect is 100 per cent. The conditions assumed in our numerical example happen frequently in the atmosphere, and, since we can refine glider design so as to reduce drag to 1/20 of lift, chances of riding the gusts would not look sad at all. However, it is very difficult for the pilot to foresee what is going to become the peak of a gust.

Besides, it is impossible to make an infinitely sudden turn. Thus one has to turn away from the gust quite a little before he gets his full share of the beneficial acceleration nor will he have reached quite the opposite flight direction on time to get all of the reverse. In addition to this, even a quite moderately banked turn consumes an additional tribute of power in the form of the increased drag induced by the increased wing-lift necessary to overcome the centrifugal force of the turn. Thus, after all bills are paid the profit is materially cut down. For instance, if one simply circled "synchronically" in a slow but powerful gust of harmonical rhythm, he may practically gain about one-third of the energy theoretically available.

On the other hand, if satisfied with only a fair fraction of the entire possible gain, you may fly across the wind and merely sway from your course somewhat in serpent fashion, correspond-

ing to the lateral accelerations, always with a trend of keeping weatherly. In fact, this is a very reasonable method to be resorted to when flying along a mountain ridge, and in some instances I am quite sure I picked some valuable gain from such lateral gusts this way. A Frenchman, Mr. A. Sée, demonstrated how energy can be gained from lateral gusts by merely rolling the machine

FIG. 10.

Spot landing.

while yielding to the yaw, so as to present the raised wing always to the luff side. However, every pilot knows this to be a somewhat delicate manœuvre, and trying it I once almost heeled over in the face of a rugged peak, having under-estimated the force of a blow which apparently shot from an adjacent gorge. The excessive banking and subsequent recovery by a dive spoiled more than all the gain.

If the gust is also accompanied by a variation in wind direction, this can be quite useful to a glider endeavoring to take those unavoidable turns always in the sense of the turning of the acceleration vector. Indeed, an optimum condition would be what may be termed a circularly polarized gust. An airplane properly curving would be centrifuged like a heavier particle in a rotary separator. Trying to head towards the pole of the whirl he would be dynamically impelled. Whether similar conditions actually occur in the atmosphere outside of tornadoes, I do not know.

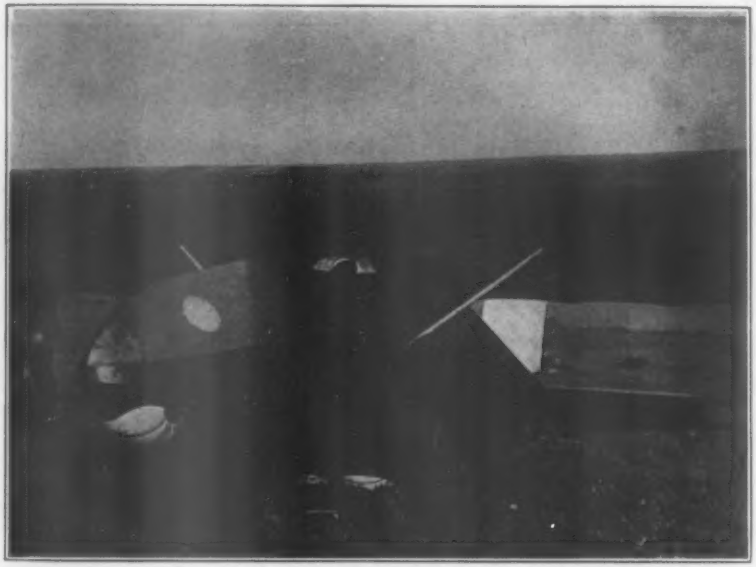
We have seen the necessity of performing some sort of a change of flight direction during the climax of a gust. But there is no reason why it is confined to the horizontal plane. Someone may prefer to do it vertically. However, by mere analogy it can be seen that it would take continuous looping the loop, synchronous with the oscillations of the gusts in order to get anything like a fair portion of the entire available energy. This is impossible. Again, a fraction of it is obtainable by performing certain vertical rocking movements. They are characterized by alternating pulling up and diving down synchronously with the acceleration phases of the gusts. The important thing about them is that they must consist of at least one primary oscillation and its first harmonic. Thus in a harmonic gust the two branches of the path will look unsymmetrical, the diving part being done somewhat steeper than the climbing. The mechanism of this performance has been compared to making a car travel uphill on a scenic railway structure by oscillating the whole structure horizontally, in the plane of travel. It is quite possible to derive some profit from occasional strong gusts by this rocking method, but it would be in vain to hope to rely on this alone for support.

Horizontal and vertical gustiness of the wind may occur combined. When they happen to be synchronous, their relative phases are of importance. Professor v. Kármán has shown that, in proximity to the ground, the surface friction causes the combination of freshening and descending or of fading and ascending to occur more frequently than the reverse. For any particle coming down from above, where velocity is greater, brings forward impulse with it; whereas any particle that happens to rise from the retarded layer below carries braking impulse with it. This reasoning would lead us to believe that an airplane flying

low over the ground would gain less when headed against the wind, but more when fleeing before the wind, as compared with what it would gain from vertical oscillations without a horizontal component.

The same principle can be applied to explain a long-known phenomenon which has puzzled early experimenters. A light wind vane balanced and mounted on a horizontal axis, intended to show the vertical inclination of the wind, seems to indicate an

FIG. 11.



Rotatable footballs as a landing gear. (Hannover.)

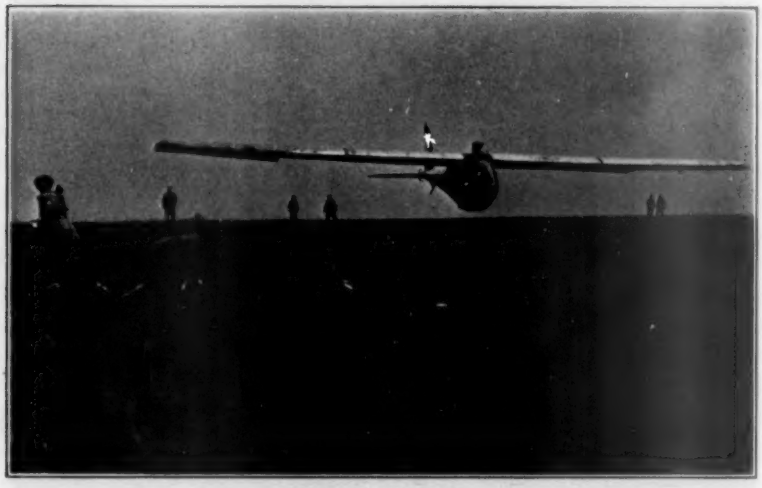
upward trend of the average of the irregular fluctuations amounting to some 2 to 4 degrees, on a level plain. Of course, the wind cannot spring from the ground. The explanation is that the rising elements are slower, the sinking elements are faster. Thus although no more air rises than falls, on the average, the apparent angle of the resultant motion is greater for the slower, and smaller for the faster particles. The mere time-average of the direction of an irregularly fluctuating vector has no physical significance.

Really measuring the vectorial fluctuations in the atmosphere is a very interesting but delicate technique. The introduction of the electrical hot-wire anemometer and directional anemometers

into micro-meteorology promises many scientific possibilities. Electrical anemometry is based on the principle of exposing a fine platinum wire electrically heated to the air-current to be explored. The temperature the wire assumes under the cooling influence of the air-flow is electrically measured or controlled and with reference to the power input gives a clue to the local velocity.

The regions of different wind-speed travel in the turbulent atmosphere and the great difficulty is to anticipate when they will

FIG. 12.



Central landing ski.

strike you. However, there are also places where they can be found quite stationary. On the leeward side of a blunt wind-obstruction there is a dead zone, a wake, so to speak, a short distance adjacent to which the wind may blow at full force. Sea-gulls, swallows and swifts are masters of the art of soaring back and forth between such layers. The mechanism of the capture of kinetic energy is very similar to that of circling in gusts. The bird glides in the dead zone towards the tower, wall, bosket or whatever forms the obstruction to the wind. Suddenly the bird weaves across the contour line of the dead zone into the open wind where, due to its inertia, it receives a powerful lift. After having made enough headway against the wind, it circles and coming down-wind shoots back into the dead zone, where the tremendous

velocity it has acquired is a big store of kinetic energy which is gradually used up in patrolling for food until it becomes necessary to resume the cycle again.

Nobody would suggest trying to duplicate such stunts with gliders, because the combination of the human brain—hands—steering mechanism—moment of inertia of the wide-spanning machine is very much slower than the corresponding chain of reaction within these birds, and chances would merely be of crashing into some rock. However, layers of different wind velocities may often be found one above the other. As a rule the wind higher up is faster than down below. The energy stored therein can be caught by alternatingly gliding down-wind in the upper layer, descending into the lower one where the relative surplus velocity is kept in reserve, then turning around and pulling up into the upper layer again. Here a powerful inertial lift is the reward of the whole manœuvre. Vultures have been seen circling this way in India, descending and ascending rhythmically in inclined orbits.

In places where the discontinuity zone separating the two layers is sharp, this phenomenon is even noticeable on regular motor airplanes. In the Karst Mountain range behind the east coast of the Adriatic Sea sometimes a peculiar meteorological condition occurs. A strong uniform westerly warm wind, called Scirocco, sweeps in from the sea at the higher altitude. Cold air, called Bora, rushes down the slopes of the bare mountains, mainly from an easterly or northeasterly quadrant. Wind-speed drops as sudden as 60 ft./sec. west against 15 ft./sec. northeast can be encountered in passing down from the 2800-ft. level to about 2000 ft. Flying there, we experienced the sensation that in trying to spiral down one way we were unable to bring the machine down to land on the flying field in the hollow, the motor throttled way down, whereas circling the other way around between the mountains, we would be knocked down so vehemently one had to open full throttle again to prevent crashing into the rocks that lined the field. It may be superfluous to mention that the inversion zone was kind of rough-riding and bumpy, too. Sometimes the altitude of the zone of wind inversion was indicated by peculiar formations of many small clouds rapidly forming and disappearing. I should not wonder if similar conditions may be encountered in parts of the Rocky Mountains also.

Even without a pronounced border surface between two distinct wind layers, there can be energy stored in accessible form where the wind is gradually increasing with altitude. This sort of power gain is most suitable for a machine capable of a high rate of climb. The gain in terms of the original rate of climb is approximately equal to the proportion of gravity to which the product of the vertical gradient of the wind velocity and the forward speed of the airplane amounts. This is the reason why

FIG. 13.

A "flapper" experiment. (Zeise.)

even above a level plain, airplanes generally climb better against the wind than before the wind, which, after the very take-off, would make no difference if the wind did not increase with height. A racer would experience a difference of about 20 per cent. in the rate of climb between the two directions of flight in an atmosphere where the wind-speed would increase by 10 ft./sec. per 1000 ft. altitude, which is not exceptional.

An interesting suggestion has been made by a Bavarian inventor, Herr Wolfmüller. His device is the true aerial counterpart to the sailing boat, and really deserves the name of sailing flight.

His argument is this: The sailboat uses a high mast to make the sails reach way up into the strong wind. Why not build the airplane so big that its upper and lower extremities extend into different layers of wind, the upper wings to act as sails, the lower ones as a keel? The idea sounds fantastic. But what he actually did is to fly two kites, one raised way up high, the other one kept low. The two strings were tied together and let go. On evenings when the wind was known to blow from the opposite direction at the higher level than down close to the ground, these kite-teams would travel many miles, and he did not always recover them. Being of rather elaborate design, they even could be stabilized at certain relative angles and made to travel across the wind at considerable speed, just as a sailboat cruises. Interesting though the principle may be, it is not very likely to be put to practical use.

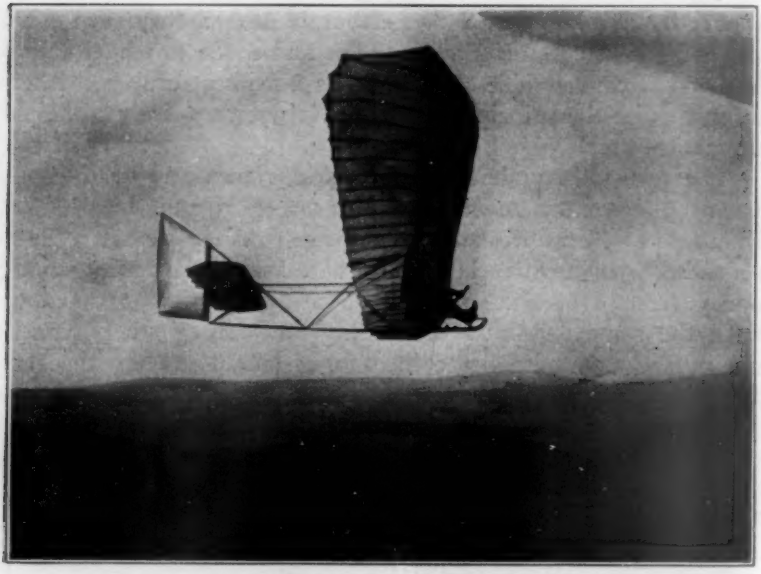
The principles underlying the various methods of dynamic soaring flight may seem to many rather remote ideas. Yet dynamical problems are not at all strange to everyday life. There is a rather peculiar financial analogy to soaring flight, viz., making money from dynamical sources. Soaring in gusts is ruled by much the same conditions as buying and selling stock, always making a change of policy coinciding as best possible with every climax. Soaring between stationary wind layers is equivalent to trading across international boundaries, buying merchandise where there is abundance of it and importing it to where it is lacking. The loss due to centrifugal force represents the import duty. Dynamic climbing in a vertical wind gradient is very strikingly paralleled by the business condition in a country where currency is being inflated, the inertia of the money devaluating during circulation being essential for the profit for those who issue it and the loss of those who furnish the values. Even the deeper cause for the maintenance of such an unstable situation being some greater disturbance of much bigger volume than the individual's concern, finds its perfect parallelism in soaring flight.

Practical soaring flight depends not only on the wind structure and the pilot's skill, but also to a large extent on the design of the glider. Theoretically, of course, any airplane can be flown as a glider provided plenty of power is presented in the aerological situation to meet the modest aerodynamic efficiency of the

machine. Extended soaring flights have indeed been made with regular airplanes, the motor just shut off, for instance by the French Lieutenant Thoret on a horseshoe-like bay on the North African coast.

The most interesting development, however, was that of the modern gliders, machines specially designed for the use without a motor. In their design lightness in spite of strength and aerodynamic refinement were carried to unusual extremes, which,

FIG. 14.



Warping wings. (Harth.)

later, did not fail to have some marked influence upon modern design of motor-driven aircraft, too.

The structures of most gliders are made of wood. Very thin plywood varying in gauge from 3/32 down to 1/32 for the total of the three plies, is the preferred material. Wooden beams and trusses joined by plywood gusset plates are assembled to the most intricate and elaborate internally trussed bridgeworks. Cantilever wings weighing less than 5 ounces per square foot are built with ample strength. Waterproof casein glue is used exclusively and nails are religiously avoided by many designers since with a well-glued joint they contribute nothing to strength

but considerably to weight and deterioration. The weight of successful gliders varies from about 250 pounds down to as little as 90 pounds. Two people can handle them on the ground.

Much ingenuity has been displayed in facilitating disassembling and road transport. This feature was a great asset for the contestants after long-distance glides in the hilly country.

In the glider field the question of monoplane or biplane has been rather decidedly settled in favor of the monoplane.

FIG. 15.

Tailless glider. (Leusch.)

Extremely large aspect ratio (= span : wing chord) became some sort of a dogma. The production of lift by wings is inseparable from evoking induced drag, proportional to the square of the load per wing span. In the glider, all protruding structures being carefully avoided to a much greater extent than is possible on a motor airplane, the more the ideal of the nothing-but-wing machine is approached, the more the induced drag becomes decisive for efficiency. Theoretically this was quite well understood. It was the merit of the gliders to have practically proved the correctness of the theory of aspect ratio and induced drag in full size. Wing spans consequently grew wider and wider and wings spanning twelve times their chord became quite common. A gliding angle of 1 : 20 was reached with them. Of course, in order to accom-

plish this it is essential also to avoid struts and external bracing, with their parasite resistance. Structurally, it is quite a task to build a light wing spanning 30 ft. from root to tip on the cantilever principle, having only 5-ft. base depth or less, at the root. Responsible designers of the old school were quite hesitating to risk something like that, so it took the boldness of college students to demonstrate that it can be done. The idea of the large wing span was in the course of events perhaps exaggerated and overemphasized by amateurs. A few accidents due to wings failing by torsion or vibration happened, although none of serious consequences to the pilots. They had the welcome effect of stimulating research on wing flutter, which since then has greatly increased knowledge for its prediction and avoidance.

The tapering of wings towards the tips has been demonstrated to contribute enough to structural and aerodynamic efficiency to justify the manufacturing complication. The gliders have done much to demonstrate the merits of the thick and semi-thick wing-sections, and the advantages of well-rounded leading edges for a wide useful range of angles of attack, whereas the particular merits of one or another special wing-section are often overemphasized.

Nowhere can the suppression of parasite resistance be carried to such a perfection as in the modern glider. Some of them resemble a bird in a striking manner. There is nothing but a wing, a tail, and a stream-lined body, just large enough to tightly house the pilot. Every aviator will agree that the field of vision from a glider's cockpit is perfect, incomparably better than from that of any regular tractor airplane. One can to the last second see the very spot where he is going to land. In fact, there was hardly anything as thrilling as the various spot landing contests which are a regular feature in glider meetings since 1922. A plot is marked, a few square feet on a lawn on a plateau a couple of miles distant from the hill where the gliders take off, and only about 100 ft. lower in level; a place which could never be reached by mere gliding without soaring. At the 1923 Rhön contest the prospective victor having alighted only 50 ft. from the goal, was quite surprised to be beaten in the last hour by someone who made 35 ft. This was considered pretty good among aces. It was only the average in last year's contests when the records followed in rapid succession: 210′, 131′, 105′, 65′, 62′, 48′, 32′, 28′,

20′, 19′, 18′, 15′, 11′, 8′, and 6′. There would be no sense in trying to beat such performances. But this reflects very strikingly the wonderful training the glider pilots acquire, too.

Glider training is lots of fun. On account of the slow velocity against the wind, and of the absence of any combustible fuel, the danger and hazards are remote. A smart high-school boy of sixteen once learned gliding in his own home-made machine by being towed like a kite and his instructor running alongside and

FIG. 16.

Wing-tip brakes. (Koller.)

shouting up to him what to do with the controls. A preferred method of training is now to first give the student some rides in a two-seater glider with dual control, before he is turned loose to solo on a very sturdy and fool-proof training glider. Then he is put on a more sensitive type for advanced training until he may try to compete in the contests on the highly refined champion machines.

A very striking development of glider design is the single-track landing gear. Wheels have been abandoned, not only for their resistance in the air, but also on account of difficulties in coming to a stop when landing on an incline. Most gliders are

equipped with skis as originally used by the Wrights. Some sort of springs are preferably inserted between skis and body. It was found quite feasible to land on one single central ski, in spite of the largest wing span. The pilot can manage lateral stability with the flaps until the machine comes to a standstill. Then it may tilt over so one wing tip may rest on the ground. A glider can safely be landed in places that would scare any motor airplane pilot to death, in underbrushes, in hollows, on steep inclines, or jumping over boskets and fences. After having stalled in the air, flying speed may be recovered after a drop of something like 25 ft.

Quite a number of rather unorthodox designs have been built and flown as gliders with interesting success. Among them are tandem wings, tailless planes, with pronouncedly swept-back wings, slotted wings, machines having the control planes in front of the main wings, and others incorporating flapping wings. An interesting experience was gained with an extremely light tail-first machine. It became longitudinally unstable when starting, due to the vertical gradient of the wind close to the ground, it is believed.

The normal gliders are equipped with elevator, rudder and ailerons, and are controlled very much like "real" airplanes. Control surfaces are often comparably large, but the length of the tail is short in comparison with the wing span. Many efforts have been made with a view to eliminating the vertical rudder. The birds have evidently quite good control without it. However, all attempts at copying the ideal warping and folding mechanism of the birds' wings or at replacing it by some other device have not so far produced anything decidedly superior to a rudder. Various kinds of wind brakes mounted on the wing tips, which on a glider have such a long leverage, have been tried with partial success. Flexible camber wings and tiltable wings have been flown quite successfully, although the advantages claimed do not seem to be exactly in proportion to the complication. Some device with which to control the gliding angle independently of the angle of attack and speed, does have some definite usefulness, however.

Some inventors believe certain special wing and steering mechanisms to be capable of performing dynamical soaring flight automatically. Such devices, it seems, are not very likely to meet with success. There is a fundamental difficulty involved, closely

connected with the problem of distinction between vertical currents and horizontal gusts and with the correct utilizing manœuvre depending on more than what can be mechanically and aerodynamically grasped from aboard. In practice, the interpretation of the sensation of equilibrium depends to a large extent on the visual observation of what happens. One can fly with his eyes closed for a while, but not a bit in dynamical soaring. Neither can a bird in pitch-dark night. Most of those inventions are

FIG. 17.

Starting the glider. (Darmstadt.)

the involuntary result of a confusion of the problems of dynamical soaring and that of stabilization in straight flight. The two problems are by no means identical. In fact, the stabilizer is intended to make the machine let the gust pass as unnoticed as possible. In dynamical soaring, on the contrary, the gust must be responded to by a vigorous motion in order to wrest energy from it. However, there is a deeper meaning to this confusion: The knowledge of the direction of gravity is a fundamental condition for any creation of a lift with which to oppose that gravity. On the solid ground or even on a big and sluggish air-liner in calm air there is no difficulty to that, and we are so familiar with it

that we are thoroughly accustomed to consider the direction of gravity as an established reference basis. Yet, on a glider performing dynamical soaring flight it becomes quite an indefinite fiction bare of sensible qualities. The reason for it is that all dynamical manœuvres involve actions of inertia, and it is just the task of the dynamically soaring machine to steer in such a way that the inertia forces do not on an average cancel out, with respect to axes inherent to the craft. Thus, dynamical soaring is

FIG. 18.

One way of hauling the glider uphill.

the true materialization of Einstein's famous fictitious box within which all mechanical means completely fail to distinguish any essential difference between inertia and gravity. Once the two are entangled they cannot be separated by instruments.

In order to describe fully the status of motion of a body freely moving in space, we have to state six elements, the three components of velocity and the three components of rotation in space. All mechanical instruments based on the principles of masses, springs, liquids, pendula and gyroscopes combined and carried on board the aircraft are subject to the combined influence of both gravity and inertia, too. So, in order to determine the vector of gravity we have to subtract from the resultant the vector of

inertia. We can measure by six aerodynamical instruments such as anemometers and wind vanes the six equivalent data about the relative motion of the ship in the surrounding air. This suffices, evidently, in calm air.

However, as soon as I suspect, or know, that the atmosphere is involved in an irregularly accelerated motion with reference to the earth, I am at a complete loss to determine the amount of the influence of this fact by means of any instruments of mechanical or aerodynamical kind carried aboard. The unknown data must be supplied by having recourse to other physical fields. In practice, I mentioned, it is the field of vision. To do that automatically by means of instruments is at present pretty well beyond available instrumental facilities. Theoretically, instruments utilizing such extraneous fields as the magnetic field, the dielectric field or the air-density gradient may be given consideration, but whether sufficient accuracy and quick response will ever be attained is hard to fancy. Besides, weight, bulk and complication are big handicaps for the use of automatic apparatus and even instruments in general.

Just the same it is of great scientific interest to investigate, with whatever instruments are feasible, into the details and intricacies of soaring flight. Recording altimeters, air-speed meters and so-called accelerometers, which, however, are really not indicating acceleration proper, but a component of the resultant air-force have been of great assistance to both pilots and students. You can, while flying, by watching these instruments simultaneously with the horizon and the other physical sensations, interpret much better whether you are gaining or losing energy, in every phase of the gust. Angle of attack and yaw meters, however primitive they may be, are also a valuable asset. A wealth of information has been accumulated lately since elaborate surveying stations were installed on the Wasserkuppe and Rossitten gliding centres. A number of continuous surveys of outstanding flights were recorded stereographically and evaluated afterwards, reconstructing the complete path of the glider in space. This work was originally started by taking synchronous readings from a theodolite and a range-finder, but later on these instruments were replaced by pairs of kinema-theodolites disposed at the ends of bases, about one-eighth of a mile long. Several pictures were thus ground per second, insuring a very dense record.

Not only true soaring flights were thus surveyed, also special straight glides were taken occasionally on particularly calm mornings. They served to get the aerodynamic characteristics of the machines themselves, independent of any soaring action.

The application of gliding to scientific research is at present somewhat limited by the method used to get the glider started. It requires the windward slope from a mountain crest, whence it is catapulted into the wind by means of a rubber cord pulled by a

FIG. 19.

Another way of hauling the glider uphill.

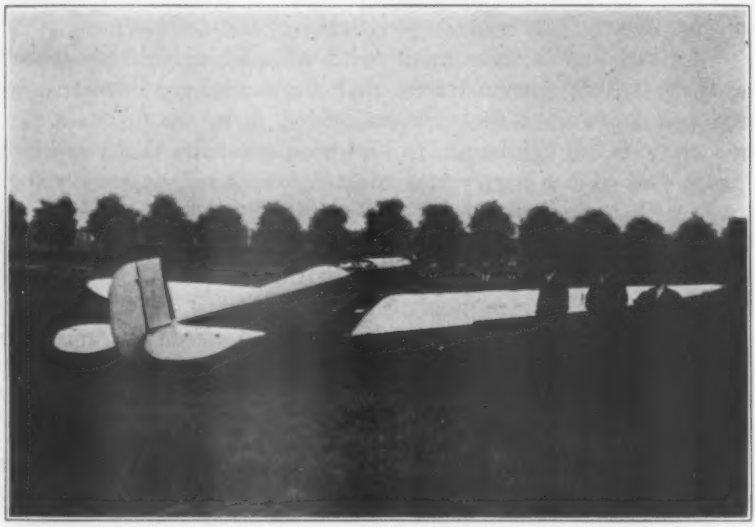
crew of from four to eight people. In hilly country this method works exceedingly well; but one had often wondered how much more gliding would be popularized if some method of take-off could be devised to depend less on topology.

I once tried to attach the glider on a captive balloon of the Swiss air service, and to take off from there. The glider was suspended some 100 ft. below the basket, slightly aft of its own centre of gravity, to keep its nose down. Unfortunately, this entire system being a gigantic double pendulum, immediately started to perform lateral oscillations. The balloon would yaw and travel to one side, the plane would prefer the opposite side. The motion was not fast but amplitudes were increasing. I was

unable to check the oscillations by use of my controls. Since the machine would also always bank toward the wrong side I was forced to cut loose only to be thrown into a spin to recover from which the altitude was insufficient.

There remains [1] the possibility of fitting the glider with a small auxiliary engine, just as they do on sailing yachts. Thus the glider may take-off in the plains and fly under its own power to any place where upon meeting soaring flight conditions, the

FIG. 20.



A typical light plane of glider descent.

engine is throttled down or shut off and the real sport begun. The auxiliary engine would also help out a glider that happens to drift away from lifting currents or runs into a dead calm. As a matter of fact, a modern glider requires no more than about 1½ HP. net for sustentation. All kinds of motorcycle engines have already been tried, varying from the smallest two-HP. variety of light European bicycle motors up to the size of four-cylinder racing motorcycle engines. Remarkable flights were made

[1] Quite recently Herren Espenlaub, Raab and Katzenstein made successful experiments by having a glider attached to and towed by a motor-powered airplane. Having been so dragged to considerable altitude, they cut loose and glided back to their base.

with such machines, taking-off on as little as 7 HP. as well as soaring with the motors shut down. Clever devices were designed for starting the engines up again while in flight. However, it soon became evident that available motorcycle engines are not thoroughly reliable and suitable under the conditions of flight. The British motor industry was the first to visualize the necessity of developing from the motorcycle engine a special light aircraft motor. Horizontal twins, 2-cyl. V-types, 4-cyl. block and 3- and 5-cyl. radial motors, now cover the range of 25 to about 60 HP. which is usually referred to as the light airplane class. All of them are air-cooled.

Startling flights were made with astonishingly low-powered machines, which demonstrated that the real light airplane, as developed from the super-efficient glider, is by no means a fine weather craft but can be put to very severe service and yet retain a great deal of the poetry and sport romance of the true glider. It was with a tiny 25-HP., 2-cyl. motor in his neat little monoplane that Botsch two years ago flew more than 300 miles from the Rhine to Berlin in three and one-half hours. A Messerschmitt two-seater cantilever monoplane of 40-ft. span, powered by a similar engine, crossed the Alps at 13,000 ft. from Bavaria into Italy under the most adverse weather conditions. Mileages as good as 60 miles per gallon are not uncommon with the light planes. The most striking feat was Botsch's victory in a competition two years ago, for a flight circling Mount Zugspitze of the Alps, 10,000 ft., starting from and returning to Munich. He won first prize with a small 14-HP. light plane against competitors of all classes, among which were motors as strong as 200 HP.; since the prize was to be awarded for the least consumption of fuel. He used only something like two gallons, doing everything else by deliberate soaring flight, skilfully utilizing the various currents in the mountainous country.

Unfortunately, among the motors at present available, there seems to be none that meets all of the ideal requirements at once, such as a really low weight per HP., fair number of cylinders insuring perfect balance on a light mounting, irreproachable reliability under flight conditions, little wind resistance, and last but not least a popular price to sell for. As soon as this goal is reached there will be comparably little difficulty to build a reliable and fairly fool-proof light airplane of high efficiency, and capable

of soaring flight, accommodating two people, slow and safe to land, of amazing fuel economy and negligible maintenance cost, the wings to fold back for housing in any garage. There is little doubt that this generation will live to see and use it and flying will become as popular as motoring. Only then, the interesting possibilities of soaring flight will be realized and the results of past research applied. Pure soaring will not fail to retain a favored rank among outdoor sports.

In Europe, gliding has contributed very much to popularize flying by bringing the younger generation into active contact with it. It is organized and stimulated by various disinterested private societies for the promotion of aviation. It is not, in general, a quick return business proposition. But I hope to have shown that it combines sport with education, art and scientific research, a combination rare in this materialistic age and not unworthy of encouragement from those who consider it a sacred privilege to contribute toward the development of new art and science.

Disease-resistant Sugar-cane Varieties Developed for Louisiana Industry. (U. S. Department of Agriculture, Press Service.)—Diseases and other damaging influences to sugar-cane production, such as mosaic infection, root rot, and borer injury, have seriously menaced the Louisiana cane-growing industry in the past few years. In an effort to improve the situation the U. S. Department of Agriculture has coöperated with the Louisiana agricultural experiment station to develop resistant or immune varieties.

One variety sent from the department greenhouses in 1922 for testing under Louisiana conditions showed such promise that it was recommended for wider use. It already has been planted on approximately 20,000 acres. This variety, together with two others now being recommended, has shown such favorable performance in comparison with the varieties formerly used that the rehabilitation of the industry is practically assured as soon as the entire acreage can be planted to these new resistant varieties.

Although these new varieties are greatly superior to the old varieties they have certain disadvantages. To remedy this the department will continue to import promising varieties, and attention is being directed toward further improvement by systematic cane breeding in the United States. A number of imported varieties tested during the crop year 1925–1926 at the Louisiana station are reported on in Department Circular 418-C, "Yield Tests of Disease-resistant Sugar Canes in Louisiana," just issued by the U. S. Department of Agriculture. Unfavorable weather conditions prevented yield comparisons in all but four of the eleven varieties planted. These four were compared in duplicate on two widely different but representative soil types, and the uniformly favorable outcome, despite the various adverse circumstances, indicates a wide adaptability of these hardy canes to Louisiana conditions.

The variety known as P. O. J. 213 was the outstanding variety and exceeded all others on the heavy soil by 500 to 1200 pounds of available sugar to the acre; but in the light-soil test, possibly because of more severe borer injury, it yielded about the same as P. O. J. 234, the new variety now being widely planted. These two varieties, when grown on a third type of soil near Lafayette, La., in comparison with the commonly grown Louisiana Purple, outyielded the latter variety by 300 and 800 pounds of available sugar per acre.

Atomic Weight of Scandium.—NICHOL H. SMITH (University of Pennsylvania Thesis, 1927, 16 pages; *Jour. Am. Chem. Soc.*, 1927, **49**, 1642–1650) has determined the atomic weight of scandium from the ratio of pure anhydrous scandium chloride to pure silver; the mean of nine analyses gives 45.160 as the atomic weight. The scandium was purified by means of ammonium fluoride and by means of ammonium tartrate. The anhydrous scandium chloride was prepared by the action of pure anhydrous carbon tetrachloride upon scandium oxide. J. S. H.

"HEARING" THROUGH THE SENSE ORGANS OF TOUCH AND VIBRATION.*

BY

ROBERT H. GAULT.

Professor of Psychology, Northwestern University, on Leave with the National Research Council.

I.

A HALF century ago Alexander Graham Bell and his associates were dreaming of what has become the omnipresent telephone; dreaming and laboring, too. The uninformed and unimaginative were smiling indulgently. Was it not a bizarre thing—the notion that a man in his shop might talk into a machine and be heard and understood next door?

It was unthinkable that a battery and a long wire should carry speech to an ear. It might be an interesting plaything for amusement within a gentleman's house and premises, but beyond that, an extravagant gesture.

Now the telephone is here and so is wireless telephony. We talk to London. We accept it as a matter of course. It is almost as near to us as hands and feet.

And here is another extravagance! A bit of pioneering that has been hitherto unventured.

I am using the principle of the telephone, together with amplification, experimentally in relation to understanding so complicated a thing as spoken language when it is carried as vibrations instrumentally to the skin of one or of several persons at once and felt as something vibrating against the skin. It is a successful experiment.

This same extravagance relates to the use of the feel of words and of connected discourse as a means for the correction of defects in speech such as those that occur in semi-mutes. Here is a door newly ajar into the applied science of phonetics.

Is it possible to feel musical sounds also and to enjoy them by feeling them? Experiment alone can answer. Preliminary work in this direction has elicited a favorable opinion.

* Read before The Franklin Institute, March 24, 1927.

Of course it is not "hearing" that I am talking about. That is a figure of speech. It is *feeling* speech and musical sounds through the organs of touch in the skin and through the organs of the sense of vibration; distinguishing the feel of one word from the feel of another and associating meanings with different "feels" exactly as we associate meanings with different sounds. There is nothing more mysterious about knowing a spoken word by its feel and about recognizing differences in pitch by their tactual qualities than there is about knowing a cake of soap in the dark by its feel.

I set out upon this adventure more than four years ago. At present, and during the last three years, it is under the auspices of the National Research Council. At the outset of the venture a speaking tube was extended through two walls in the intervening room. A student—now one and now another—held his hand tightly over one mouth of the tube. I discovered that when the vibrations of air from an experimenter's mouth in the act of speech were thrown into the farther end of the tube the student could feel the quivering air within it. Then I found that he could distinguish one word from another and ultimately he could identify members of a group of thirty-eight different words. That gave me a start, though it was a very crude one, in a virgin field.

Electrical appliances were then substituted for the tube. The first instruments were rough enough. They have been improved.

Remember that the skin was the original ear. If James Harvey Robinson in writing his "Mind in the Making" had gone back farther than he did go toward the beginning of the development of thought and prejudices, he would have observed that the most primitive man did not hear with his ears and obtain original data through that source, for the mollusk of old, like the mollusk of to-day, had skin and no ears. He *pricked up his skin* and *felt* his environment.

In this adventure we are, in other words, going backward over the genetic history of our organs of sense to the great, undifferentiated "mother sense of them all," and we are looking forward to a time when those who are bereft of the most complicated organ of touch—the hearing ear—may fall back upon the very base of the sense of reality in the extended array of organs of

touch in the skin. From an unaccustomed angle we are here entering upon the great archæological field of the psychologist.

Before I get beyond preliminaries I should say a little at least in reply to the inevitable query from the uninitiated: "How do you get your speech over to the 'listener's' skin?" Later in the course of this paper I shall go into some detail in answer to this question.

Imagine a group of persons, each of whom holds a vibrator in his hand. Each device is analogous to the ear-piece in a radio set. In its own place each one serves the same purpose. Through suitable batteries and an amplifier these devices are connected with a transmitter or microphone. Now assume a speaker; let him be out of the subjects' sight and any distance away, if only he is before the transmitter so that his vocal vibrations beat upon it. Then the moving element in each vibrator hidden in the hand of the "listener" begins to work against his finger-tip and he knows at once that something is "going on." Now, if the speaker's assistant before the eyes of the subjects will use a blackboard, a piece of chalk and a pointer, they—the "teletactile auditors"—will soon discover that one thing happens against their finger-tips when the word *a* falls from the speaker's lips into the transmitter at the other end of the system, and another thing when *o* is uttered, and quite a different thing when the word is *elephant*. In like manner to the end of the alphabet and dictionary. By and by, the folk who are holding the vibrators can get on without the assistant and his blackboard and can travel the road alone.

II.

My experiments are of primary interest to psychologists and physicists. They reveal an undreamt of capacity for refinement of discrimination within the realm of the senses of touch and vibration. They demonstrate the possibility of using these senses as the base of supplies for the process of integrating a language sense. We are here substituting one sensory function for another —a process, the like of which, we have been studying anew since the war. I will trace the larger outlines of my results.

(1) Two deaf people who had been working in my laboratory during an aggregate of 290 and 280 hours, respectively, to May,

1926, were able in that month to pick up a story from the feel of it when the speaker was out of sight. This is no more uncanny than is learning to know any other thing in the dark by its feel.

(2) Other subjects, less experienced, have learned to recognize many sentences, words, certain vowel and diphthongal qualities when they stand alone, and to make a fair showing at identifying these elementary qualities when they are found in words that had never before been felt as words.

(3) I have demonstrated an improvement in speech on the part of my deaf-mute or semi-mute cases; in the modulation and lilt of the voice; in emphasis, rhythm, accent and tempo. In enunciation, too. The feel of the movement of speech gets "into their bones." Then they speak better than they formerly did. And that is not extraordinary. The rôle of the kinæsthetic sense in the psychology of movement is in the psychology of speech, too. Speech is a form of movement. We dance as nicely as we do because we have the feel of the music in our bones. When a deaf person speaks a given phrase through a microphone against his own skin he is able to compare the feel of his own voice with what occurred a moment before when the experimenter uttered the same phrase. He thus obtains an intimate feeling for the way speech normally runs along through cadences and tempos from phrase to phrase. It is a vivid experience for him. Out of it come cues to guide him in his own speech.

Between January 26 and March 4, 1927, one subject made an improvement of 38 per cent. in speech—measured by the accuracy with which strangers out of her sight could understand and report what she was reading aloud. She had already graduated from a school for the deaf and was having no training outside our laboratory.

(4) We have demonstrated an improvement in reading capacity in the course of an aggregate of no more than twenty hours of laboratory training.

(5) One case without hearing and without vision of the speaker's face attained to perfection in recognizing 120 colloquial sentences when she had felt each one but nine times; thirty to-day and thirty to-morrow till the whole series had been finished; then another going-over in a different order. Others in the same time attained to from 60 per cent. to 90 per cent. of perfection. After

the ninth reading 72 new sentences were mingled with 108 of the old ones without the subjects' foreknowledge. On the first trial thereafter the most successful case not only recognized new sentences as new, but she interpreted 28 of the 72 new ones in addition to the 108 old ones.

This is not the knowing of so many scores of isolated words by feeling them. It is the recognition of some words as such; of many vowel and diphthongal qualities, and of many more

TABLE I.

Improvement in Reading.

Subject.	November 17, 1926.	February 28, 1927.
	Per cent.	Per cent.
O.	80	87.5
C.	82.5	90
S.	62.5	60

Subjects indicating by a check the best of three methods of reading each one of 40 sentences.

S. discontinued laboratory exercises shortly after November 17th.

envelopes or patterns of phrases and sentences as wholes. It is also the interpretation of all these things.

(6) From the feel of the movement of spoken language subjects have acquired some of the thrill of speech. It has been made to live for them. Both prose and verse afford them pleasure, but not all in equal degree. The verses by Southey, for example, on "The Waters of Lodore":

> "How does the water
> Come down at Lodore
> From its sources that well
> In the tarn by the fell"—

are particularly pleasurable. They ask the experimenter to repeat a reading of these verses. They prefer them to the following line from Stevenson, though it is in the same meter as the Lodore verses:

> "How do you like to go up in a swing?"

The only difference between these verses is in the predominant vowel quality. Evidently some vowel qualities are more pleasurable than others. Isn't it odd that one can find pleasure in feeling

TABLE II.

Recognition of Certain Final Consonants and Semi-vowels.

January 21, 22, 24, 25, 26 and February 7, 1927.

Times Given.	*ee*	*eep*	*eet*	*eek*	*eed*	*eel*	*eer*	*eem*	*een*	*eeng*
27	21									6
ee	77.8%									22.2%
28	2	9	6					1	3	7
eep	7.1%	32.1%	21.4%					3.6%	10.7%	25.0%
28	1	11	13	3						
eet	3.6%	39.3%	46.4%	10.7%						
28		1	6	18	3					
eek		3.6%	21.4%	64.3%	10.7%					
28			1	2	25					
eed			3.6%	7.1%	89.3%					
28						16	9	2	1	
eel						57.1%	32.1%	7.1%	3.6%	
28	2					6	17	1	2	
eer	7.1%					21.4%	60.7%	3.6%	7.1%	
28								18	8	2
eem								64.2%	28.6%	7.1%
27	3	1						1	14	8
een	11.1%	3.7%						3.7%	51.8%	28.6%
28		1						1	11	15
eeng		3.6%						3.6%	39.3%	53.6%

In the heavy-boxed squares are the number and per cent. of identification of each stimulus. Other figures represent confusions. Thus the figures 2, 9, 6, 1, 3 and 7 in the second row of squares from the top indicate, respectively, that when *eep* was pronounced, *ee* was reported twice; it was identified nine times; *eet* was reported six times, etc. *Eep* was pronounced 28 times.

such things upon one's fingers? But there are stranger things. What is delectable about a pinch of snuff in the nostril aside from the opportunity it affords to flash a delicately carved snuff-box? I do not know. Some behave as if they enjoy it, and that is the rock-bottom fact. We can learn to enjoy almost anything excepting condescension on the part of our neighbors.

(7) We who hear are deceived if we think we have an ear upon every consonantal quality in speech. What can the fingers do? I have only begun to enquire of my own thumb. On six days, a half-hour session daily, I have tried to identify certain consonantal and semi-vowel qualities following long *e*. A given tactual impression may be any one of ten. I have made identifications of each syllable in a certain per cent. of cases as set out in Table II. When this type of work shall have been completed for all our vowel qualities, both preceding and following consonantal elements, we shall be in a position to offer a satisfactory answer to the consonant query. Meanwhile the outlook is favorable.

I doubt if identification is by means of the quality of a consonantal element as a unit taken alone. Not in all cases at any rate. The judgment is often based principally upon the way in which the tactual quality is cut off and by the interval that lapses between it and what follows or precedes it. As far as we have gone, what follows the vowel is a sharp punch that corresponds to *p* or *t*, or a dull one that occurs with *d*, *k*, or hard *g*. If it is not in these categories it is a slight fading away of the tactual experience, as in final *n*, or a marked fading, as in the nasal *ng*, or a swelling out, especially with the liquid *l* and less of it with *r*, or a longer or shorter interval between what stands for the vowel and what stands for the consonant. This description is based upon experience with a single-unit vibrator or receiver analogous to that in a radio set.

(8) Up to this point I have had in mind a situation in which the experimenter is hidden from the subject. But let him simultaneously see the speaker's face and feel his words. An important result occurs: He can then understand what the speaker says anywhere from 30 per cent. to above 100 per cent. more perfectly than he can do by lip-reading alone, assuming that he has had *only 60 or 70 hours of training*. This is an extraordinarily important point because of its practical bearings. Herein is the possibility of enormously speeding up instruction of the deaf.

(9) Because the deaf can enjoy the feel of verse more or less according to its predominating vowel qualities, why not music? The answer is that they can. When one of them consistently reports to me that he prefers "Old Black Joe" when it is sung into his chest through a vigorously acting receiver that makes

TABLE III.

Order of Difficulty in Recognizing Certain Consonants and Semi-vowels Following Long "e."

February 7 to March 1, 1927.

Fifty judgments on each pair excepting as noted.

All 100%.		All 98%.	All 96%.	All 94%.
ee — eel *ee — eer* *eel — eep* *eel — eet* *eel — eek* *eel — eed* *eel — eeng* *eep — eer* *eep — eeng* *eer — eet* *eer — eek*	*eer — eed* *eer — een* *eer — eeng* *eet — eem* *eet — een* *eet — eeng* *eem — eek* *eem — eed* *eek — een* *een — eed* *eed — eeng*	*ee — eek* *ee — een* *eel — eem*	*ee — eep* *ee — eem* *ee — eeng* *eep — eem* *eek — eeng* *eeng — eek*	*ee — eed* *eel — een*
90%.	86%.	83%.	82%.	79%.
ee — eet *eep — eek* *eep — eed*	*eep — een*	*eer — eem**	*eel — eer** *eet — eed*	*eem — een**
76%.	71%.	68%.	67%.	59%.
eek — eed†	*eep — eet**	*eet — eek‡*	*eeng — eem**	*een — eeng**

* 100 cases. † 150 cases. ‡ 200 cases.

In this table "100%," *e.g.*, means that *ee* and *eel*, etc., were always recognized, respectively, when they were paired.

itself felt throughout the wall of his thorax and prefers it to every one of nine other songs and hymns, we have good ground for the affirmation: All the better ground in this instance because the subject never knew in advance what was about to be sung. After six weeks, furthermore, he was able to do fairly well at indicating by sign the rise and fall of the singing voice of the experimenter.

All these are so-called "practical" results. "Practical" because, in this case, they have a direct relation to certain situations in the world of education. And that, I believe, is what all science is in its beginnings. It is "practical" in the sense of having a direct relation to human wants. Remoter problems emerge and lay hold upon our attention as experience grows from more to more. In this connection they are beginning to appear.

TABLE IV.

Comparing Lip-reading with Lip-touch-reading.

May 6, 1926. Miss T., experimenter; using two sets of sentences containing ten each, which were of equal difficulty from the lip-reader's viewpoint. Each set of ten sentences contained exactly 114 words. The results are not expressed in terms of per cent. The experimenter gave ten sentences for lip-reading followed by ten for lip-touch-reading.

Number of Stimuli.	Words 114 114		Sentences 10 10	
	Correct. Lip.	Lip-T.	Correct. Lip.	Lip-T.
F.	112	100	9	6
N.	43	76	0	4
Cl.	70	79	3	4
Br.	25	51	0	1
A.	40	75	2	4
	290	381 31.3% gain	14	19 35.7% gain
Excluding F., who had been in the laboratory only ten sessions to this date.		57.8% gain		160.0% gain

C., experimenter; using the same two sets of sentences but reversing the order of presentation; that is, giving to another group of subjects ten sentences for lip-touch-reading first, followed by ten for lip-reading.

	Lip.	Lip-T.	Lip.	Lip-T.
K.	47	59	1	3
Bu.	60	78	2	4
J.	45	89	2	3
N.	50	71	1	3
	202	297 47.0% gain	6	13 116.6% gain

TABLE IV (*Continued*).

January 26, 1926. C., experimenter, using two groups of 58 sentences. One group contains 529 words, the other, 507.

Number of Stimuli.	Words 529	507	Sentences 58	58
	Lip.	Lip-T.	Lip.	Lip-T.
	Per Cent.		Per Cent.	
B	49.0	44.9	5.1	10.3
M	39.8	45.4	6.8	6.8
N.*	73.2	81.9	22.4	25.6
Cl.	60.7	62.7	15.5	27.5
A.	52.5	78.1	15.5	51.7
H.	92.0	92.2	67.2	77.5
Ca.	55.9	62.4	12.0	18.9
A.*	62.4	92.4	8.6	37.9
Group total.	485.5	560.0 15.3% gain	153.1	256.2 67.4% gain

* Took the first 30 of the 58 sentences.
These subjects, excepting Cl., K., Bu., J. and Ca., had had approximately 100 hours of laboratory training before the tests were made.

I have long felt that a contribution is likely to flow from this adventure to the science of neurology. More than this it has seemed to me very probable that the technique I am developing will be serviceable in studying the psychological processes of integration that occur in the course of the development of a language; this for the reason that the method offers an approximately rigid control of the conditions in which we may observe these integrations as they occur in the course of learning a foreign language—and this is the foreignest of all: The vibro-tactile language. There are already indications that my feeling or guess is being shared by others.

What I am reporting at present, therefore, is only upon the edge of a vestibule that leads into a maze of enticing avenues of science. The door is only beginning to be set ajar toward hitherto unrealized capacities of the psychophysical organism for becoming acquainted with its world. Before I conclude this discussion I shall make use of such detailed results as are pertinent to the particular aspects of the general subject that may be in hand.

TABLE V.

Lip and Lip-touch Tests.

January 20, 1927.

1.

		Sentences 58 (A)	58 (B)	Words 529 (A)	507 (B)
Subj.	Exp.	Per Cent. Correct. Lip.	Lip-T.	Per Cent. Correct. Lip.	Lip-T.
O.	G.	15.5	37.9	56.3	74.5
C.	G.	12.0	10.0	44.2	47.3
B.	C.	8.6	20.6	44.2	53.6

2.

		Sentences 58 (B)	58 (A)	Words 507 (B)	509 (A)
Subj.	Exp.	Per Cent. Correct. Lip.	Lip-T.	Per Cent. Correct. Lip.	Lip-T.
O.	C.	53.4	60.3	73.3	82.7
C.	C.	22.4	29.3	60.9	67.2

3.

		Sentences 18 (B)	18 (A)	Words 155 (B)	161 (A)
Subj.	Exp.	Per Cent. Correct. Lip.	Lip-T.	Per Cent. Correct. Lip.	Lip-T.
O.	C.	12.0	13.7	68.3	77.6
O.	C.	6.8	5.1	58.0	60.2

The total number of sentences employed was 116, divided into two lists as nearly equal in difficulty for the lip-reader as possible. These were chosen from the Muller-Walle text for lip-readers. These two lists, called (A) and (B), contain 58 sentences each.

On the morning of January 17, 1927, G., Exp., used 40 from each list during the experiment in the following manner: 20 lip; 40 lip-t.; 20 lip. The following morning he pronounced the remaining 18 in each list as follows: 18 lip; 18 lip-t.

C., Exp., reversing the lists so that the sentences employed by G. for lip-reading were used for lip-touch, etc., began on the afternoon of January 17, 1927, a retest of the subjects O. and C. The order of stimuli was: 10 lip; 20 lip-t.; 10 lip. The following afternoon C. continued in the same manner with an equal number, and concluded the two lists on January 20, 1927, in the afternoon, using the order: 9 lip; 18 lip-t.; 9 lip.

When testing B., C. used the stimuli lists in the same manner as G. had done, excepting that on January 17th he gave 10 lip; 20 lip-t.; and 10 lip. The next afternoon he gave 19 lip; 38 lip-t.; 19 lip.

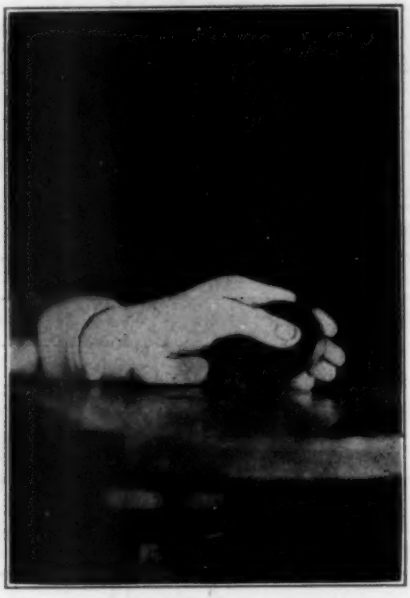
The data in 3, although incorporated in the results shown in 2, are set down separately. Here there were two utterances of each sentence in both the lip and lip-t. lists. One was given with face screened; the other with face exposed. The circuit was on and receivers acting, but they were not touched by the subjects in the lip-reading portion of the test. This method was used to equalize possible auditory cues.

These subjects had had approximately twenty hours of training before the test was made.

III.

Now is the time to describe the means by which the vocal expressions of the experimenter are translated into tactual impressions upon the skin of our subjects. All members of a group simultaneously are equipped with receivers or teletactors which are held in their hands. The subject's finger or thumb rests lightly upon a diaphragm that vibrates with the experimenter's

FIG. 1.



Thumb of a subject resting upon the diaphragm of the single-unit receiver.

voice. The region of resonance of the diaphragm is around 900 d.v. A carbon transmitter of high quality is at the mouth of the experimenter. A six-volt "A" radio battery, a Philco Eliminator, Power B, as a substitute for the "B" battery, and a Western Electric 7-A three-tube amplifier complete the outfit. All this apparatus, excepting the battery and the eliminator, I have through the courtesy of the Bell Telephone Laboratories.

Unfortunately this method of applying the stimulus leaves some physical factors out of control. It is impossible to be assured that all subjects hold the receiver in precisely the same

way; that is, we cannot know of a surety that they all exert precisely the same pressure upon the diaphragm of the teletactor, and that they are all in contact with corresponding areas upon it. For that matter we cannot be certain that a given subject behaves uniformly in these respects day after day. Such irregularities introduce more or less lack of uniformity of stimulation amongst subjects simultaneously, and in relation to a given subject from time to time.

Once more. I have said that the period of resonance of this

FIG. 2.

Group of deaf subjects at work. Each one holds the receiver in his left hand. All simultaneously receive the same impression.

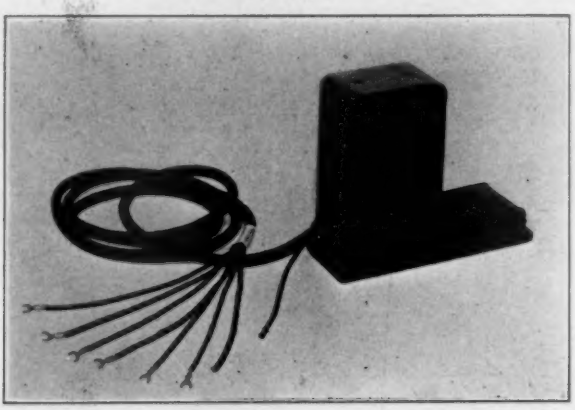
receiver is around 900 d.v. For this reason when one pronounces *ah* as in *father* into the system it comes upon the skin through the teletactor with a great emphasis, because its characteristic frequency is in the vicinity of 900 d.v. also. It is next to impossible to avoid stressing *father,* in the phrase: "My father and mother were Irish," however much one may want to bear down upon *mother.* It is like giving a push to a car that is supported upon ball-bearings. The thing moves and gathers enough impetus in a short space to crash through the wall of a house. Lacking ball-bearings it moves sluggishly and may be brought to a stop by an adverse breeze.

It is impossible to be assured, furthermore, that a given subject constantly maintains the very same area of his skin in contact with the diaphragm. I do not mean to imply a certainty that it is important to do so.

I have said that we are not able to control these factors; and it is impossible, certainly, without harnessing the subject in such a manner as to interfere with the freedom of his responses.

The instrumental situation I have described would be much simpler from the subjects' standpoint if some analysis of the stimuli could be made upon the skin; if, for example, the felt

FIG. 30.

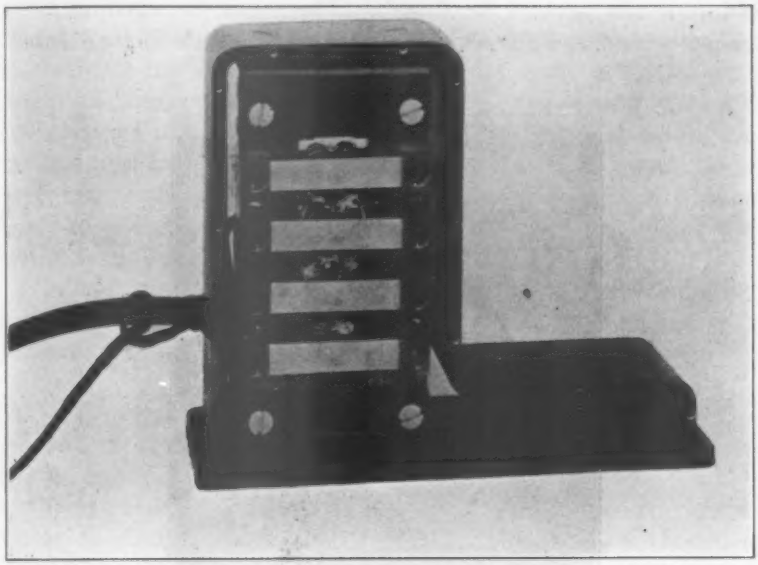


Multiple-unit receiver or "teletactor." The contacts through the housing for the four fingers, respectively. On the reverse side is a contact for the thumb. Each contact is a post set upon the middle of a vibrating reed.

vibrations could be distributed over a large tactual area according to their frequencies. Such an arrangement would add one criterion for discrimination (location of stimulus) to those that are available to subjects who use the receiver I have described. In that case, the instrument upon the skin would perform a function in relation to tactual experience that crudely parallels the function of the basilar membrane in relation to hearing. It would be like grafting an ear upon the skin.

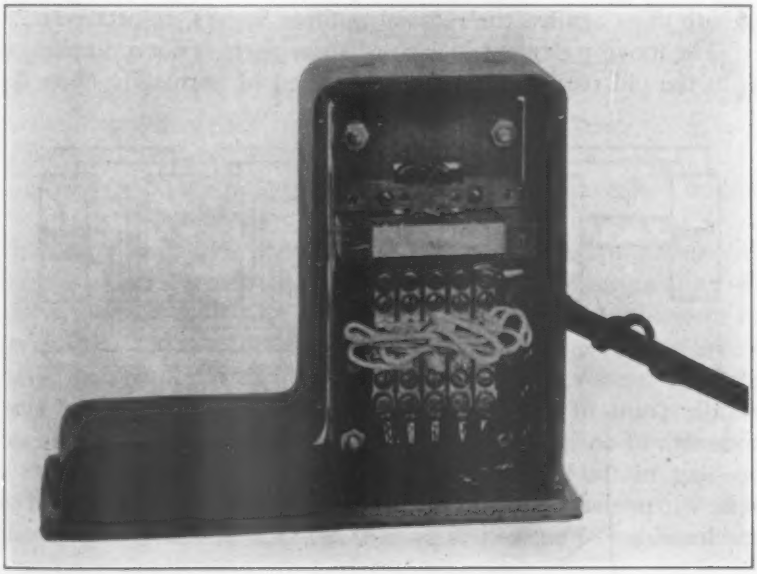
Such an instrument is now at hand. It has been designed and built through the generosity of the Bell Telephone Laboratories. It has five vibrating units, or parts, instead of one as in the older apparatus. It employs a filter to break a certain total range of vibrational frequencies that are employed in speech into five

FIG. 3*b*.



The reeds of the multiple-unit receiver or "teletactor." Four on this side for the fingers, respectively.

FIG. 3*c*.



The reeds of the multiple-unit receiver or "teletactor." One on this side for the thumb.

segments. Those that lie within a given segment up to 250 d.v. operate a unit against the thumb. The segment including 2000 d.v. per second and above operates against the little finger. Inter-

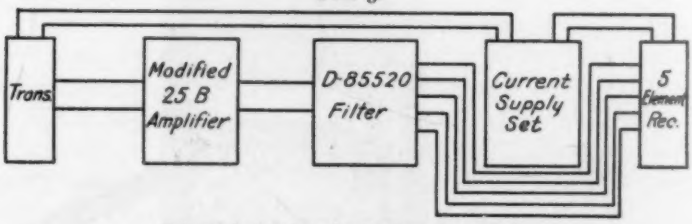
FIG. 4.

Hand of a subject grasping the multiple-unit receiver.

mediate segments, 250–500, 500–1000, and 1000–2000 d.v., actuate units against the remaining three fingers, respectively.

The moving element in each of these parts is not a diaphragm as in the old receiver, but a narrow reed of permalloy upon the

FIG. 5.



Schematic drawing of tactual receiver circuit.

middle point of which there is set a short post of steel one-sixteenth of an inch in diameter. The post works within a round opening in the housing of the instrument, endwise against the skin. It projects one sixty-fourth of an inch beyond the wall of the housing. The reed is so stiff that its vibrating can hardly

be drowned by crowding a finger against the projecting post. The pressure factor, already alluded to, is in no need of control. The post insists upon being noticed. The diaphragm in the older receiver, on the other hand, easily subsides under a pinch. Furthermore, the period of resonance of the reed is near the outer boundary of the sense for vibration. It is beyond the range of the essential speech frequencies. No felt quality of speech, therefore, can catch it like a gust of wind upon the heels of a rising tide and pile it upon a finger. Emphasis of speech, in this teletactor, must keep its own natural place.

In operation the new receiver requires a two-tube amplifier, four six-volt storage batteries or their equivalent, and a source of 110-volt alternating current. All this in addition to a filter.

IV.

So much for the mechanism by which spoken sounds are applied to the skin.

Who are the people who lend their skins to this experiment? Three normally hearing and speaking people who are trained in the methods of psychological research and whose interest is scientific. They are indispensable in analytical work by which we aim to survey the land in advance and lay out the ways of approach. They are employed in sound-proof situations. There have been a total of twenty-seven deaf subjects whose ages range from seven to thirty-five. No one of these has hearing for speech even when aided by an acousticon and amplifier. Their degree of deafness to simple tones ranges from absolute to 50 per cent. Eighteen of these are reported as congenitally deaf.

The laboratory practice that these subjects have had covers from four months to two academic years. Daily work of from a half hour to an hour is the rule. The very minimum number of judgments for record that a subject will make in relation to stimuli in the course of four months is 3000. The minimum in the course of two academic years is 24,000. The least total number of judgments of each of twenty of our twenty-seven subjects is much nearer 24,000 than 3000.

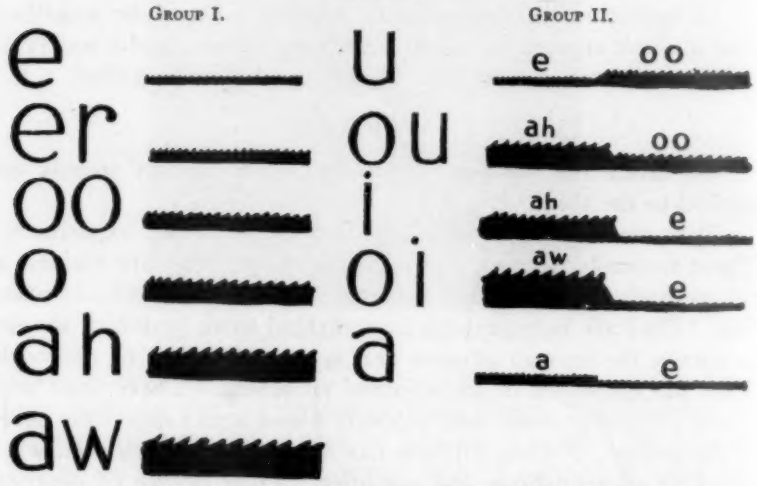
I have made these statements to drive in the point that our cases are no mere novices in our laboratory situation. We are interested, however, in observing what a novice can accomplish in certain experimental situations. I shall report, for example,

how rapidly beginners have progressed in learning to identify vowel and diphthongal qualities by their tactual qualities.

V.

What is the nature of the stimuli? Roughly speaking they are sentences and words chosen from the English language and certain vowel, diphthongal and consonantal elements of words. The elements we have employed to the present are the following vowel, semi-vowel and diphthongal qualities: *e* (eat); *er* (refer);

FIG. 6.



Key to vowels and diphthongs. Indicating relative "weight" and roughness.

oo (boot); *o* (so); *ah* (father); *aw* (aw); *u* (you); *ou* (bout); *i* (sigh); *oi* (oil); *a* (ate). In addition to these are final consonants and two semi-vowels combined with long *e* as follows: *eep, eet, eek, eed, eel, eer, eem, een, eeng.*

How many words in isolation from sentence structure and how many sentences have been employed in our numerous types of exercise? In the aggregate they mount to several hundreds. A deal of specific drill has been had in relation to 66 isolated words and to 120 sentences that have been systematically chosen for the purpose.

Details are not lacking as to the way in which vowels roll over a finger. In relation to hearing, vowels and diphthongs are the energy carriers. So are they through the teletactor in relation to

the tactual sense and the sense of vibration. Our subjects themselves have described the six vowel qualities I have mentioned in terms of their intensity or "weight," as they say. From *e* to *aw* is an increasing order of weight, *e* is lightest and *aw* is heaviest. In exactly the same order they have ranked these qualities in terms of roughness to the feel: *e* is smoothest and *aw* is roughest. I am referring now to twenty deaf subjects, each of whom made approximately 3800 judgments while he was arriving at this description. At the end there was practical unanimity amongst them in respect to their judgments of relative weight (intensity) and roughness. They used these criteria very successfully in their attempts at identifying vowel and diphthongal qualities by their feel. The measure of their success at the completion of the drill is indicated by 80 per cent. to 100 per cent. of a perfect score.

We have undertaken to discover in how short a time a deaf subject who has never heard human speech and who has had no previous laboratory practice of this nature could learn to make use of these tactual characteristics in the identification of the vowel and diphthongal qualities I have mentioned. For this purpose we selected a young woman twenty-two years of age and began intensive work with her on October 16, 1925. In the course of twenty sessions of a half hour each she learned to identify ten of the eleven qualities I have already quoted (excluding only *ah*) in 83 per cent. of instances. During this period she made 1200 judgments for record. She had not the advantage of the graduated order of weights and roughnesses of the vowel qualities to which I have alluded, at any rate her attention was not called to them.

On March 25, 1926, we undertook the same intensive program with a congenitally deaf boy aged twenty-three, who up to that time had never been inside the laboratory. He had the advantage of the description of qualities I have mentioned. The experimenter over and over again brought them to his attention. In twelve sessions (720 recorded judgments) he attained an accuracy of 83 per cent.

These experiences admit at least an initial ray of light through a crack in the shutter upon the ever-recurring question: "How rapidly can one learn to use the tactual criteria of speech?"

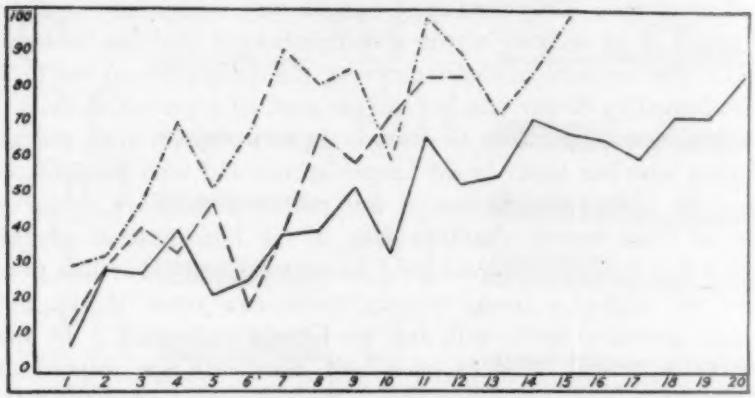
The five diphthongs, mentioned above, our subjects recognize

as combinations of the roughnesses and weight of vowel qualities. Thus *u* combines *e* and *oo*.

From my own experience as a hearing subject in these experiments I feel sure of only one change that I would make in the order of the vowel qualities I have mentioned. To repeat, the deaf subjects ranked them in order of weight and roughness: *e, er, oo, o, ah, aw.* I would make *er* and *oo* change places.

It is certain that the roughness of these qualities and their intensity, too, in parts of the series at least, has a relation to the

FIG. 7.



Learning curves on ten vowel and diphthongal qualities. Three subjects. Figures in the horizontal line represent successive laboratory sessions of approximately thirty minutes each. Figures in vertical column indicate per cent, of perfect identification. The two lower curves represent the experience of subjects who were just beginning their laboratory practice. The uppermost curve represents the progress of a subject who had just returned to the laboratory after an absence of two semesters, prior to which she had had tactual training of this nature during an aggregate of approximately thirty hours.

character of the receiver. Even so, it will be observed that the order I have quoted approaches very closely to that of fundamental frequencies that characterize these vowel qualities. I refer to Crandall.[1] He found the mean fundamental frequency and the mean low characteristic frequency of four male voices and four female voices given in Tables VI and VII.

It is improbable that there is a great difference between the figures of Crandall and the corresponding frequencies of the experimenter's voice in our laboratory. It will be noticed that if *oo* were placed over *e* in the scale our deaf subjects' description would correspond exactly to the descending order of fundamental

[1] "The Sounds of Speech," *Bell Sys. Tech. Jour.*, **4**, No. 4.

frequency according to the figures in the table. I have alluded also to the fact that, relying upon the story of my own fingers, I should make *er* and *oo* change places. Not only so, but I have lately found deaf subjects who, without my asking them for a judgment, have expressed the opinion that *oo* is lighter upon the finger than *er*. Thus do our approximations grow and grow.

Of course I understand that one in the east and south and midway between is playing with an ammunition dump when one handles this much-knocked-about *er*. Some of us ignore it in speech, others tip our hats to it and still others grind it with an

TABLE VI.

Mean Fundamental and Mean Low Characteristic Frequencies.

	Male Voices.		Female Voices.	
	M. F. F.	M. L. C. F.	M. F. F.	M. L. C. F.
e	136 d.v.	296 d.v.	252 d.v.	332 d.v.
er	131	570	239	712
oo	140	411	270	581
o	116	520	237	729
ah	113	955	234	1036
aw	112	722	243	801

ominous sound. As to the other qualities in our list, there are individual differences, too, in the matter of pronunciation, and it is improbable that any one of us holds absolutely from day to day to a fixed mode of uttering any one of them. But in spite of these inequalities our subjects get ahead. Not even the voices of strangers foil them. Thus the average of a group of six cases fell off from 73 points on a scale of 100 to 53, and a group of five fell from 80 to 53 when complete strangers were pronouncing sentences into their fingers. This is altogether encouraging in view of the fact that no one of the groups had had more than seventy hours of training prior to the test. This statement relates to a situation in which sentences are the stimuli and in which the swing of speech is a factor in recognition. This we demonstrated two years ago. Much more recently we have shown that it obtains also in relation to the very much simpler and more difficult situation when the stimuli are vowel and diphthongal qualities and when a woman's voice is substituted for a man's.

It is entirely probable that subjects find some criteria in addi-

tion to intensity and roughness. I am thinking of a felt pattern of vibrations that they may obtain from the diaphragm of the receiver. For when it is vibrating freely in the air it falls into a pattern—no two alike when a series of vowel qualities, *e.g.*, are spoken into the transmitter. The novice can see these patterns with his unaided eyes. If he will sprinkle a powder lightly and evenly over the diaphragm of a receiver in a horizontal position

TABLE VII.

Order of Difficulty in Recognizing Certain Vowel Qualities Taken Two at a Time.

G. Subject, January 31 to February 3, 1927.

50 judgments on each pair.				On February 7, 1927, G. repeated 50 each
		Per cent.		Per cent.
1 — *e*	— *o*	— 100		
2 — *e*	— *ah*	— 100		*er* — *oo* — 80
3 — *e*	— *aw*	— 100		*ah* — *aw* — 76
4 — *oo*	— *o*	— 100	1	
5 — *oo*	— *ah*	— 100		
6 — *oo*	— *aw*	— 100		
7 — *er*	— *aw*	— 98	2	
8 — *er*	— *o*	— 96	3	
9 — *e*	— *oo*	— 96		
10 — *o*	— *ah*	— 92	4	
11 — *er*	— *er*	— 90		
12 — *er*	— *ah*	— 90	5	
13 — *o*	— *aw*	— 90		
14 — *er*	— *oo*	— 60	6	
15 — *ah*	— *aw*	— 54	7	

100% means that *e* and *o*, *e.g.*, were recognized, respectively, in every instance in which they appeared.

and speak into the microphone end of the system, the skin of powder dances about and settles into a figure, now one and now another, depending upon the vowel quality that he is uttering.

Can the subject catch these vowel patterns on the wing? The physicist replies that they change profoundly the moment ever so light a pressure is brought to bear upon the vibrating element. Nevertheless, if I may anthropomorphize, it doubtless tries to vibrate according to its nature and incipiently it does so. Is it possible that the touch organ may seize upon the incipient figure? The question raises doubts, but let us not shut the door.

Certain variations amongst subjects' reports may be due in some measure to the fact that one has succeeded in catching some of the details of a pattern and that he throws these criteria into the hopper along with distinctions of intensity and roughness, while another fails to pick them up. He must do his business of judging, therefore, with a small range of capital: With fewer criteria than his neighbor has at his command. Thus one subject finds *oo* one of the most easy qualities to discriminate from the other ten in the list. For another, working simultaneously, it is one of the most difficult; this may be for the reason, in part, that one catches the pattern while another does not.

In the preceding discussion I have had in mind the single-unit receiver. It is of essentially the same order as the ear-piece of a radio set. As to the new five-unit teletactor already described, it yields a pattern without question. But no post or immediate stimulator alone does it. The posts plunge against the skin, some more distinctly than others, and some less, depending upon the segment of frequencies that actuates it. A given post acts with more or less intensity, depending upon its driving power at a given moment: Whether it comes from a higher or lower section of its corresponding segment of frequencies. Two or more of them acting in succession or simultaneously present a pattern. Thus, to take a hypothetical example which, by the way, is not true to fact: The word *a* is a diphthong. In uttering it we begin with a low frequency and conclude on a higher level. Suppose the frequency at its beginning is below 250 d.v. and at or near its ending between 1500 d.v. and 2000 d.v. Assuming that no other frequency segments are represented, this word—diphthongal quality—will be felt first upon the thumb and last upon the fourth finger. Its pattern, then, is 1–4 (if the figures represent the fingers of the hand, including the thumb). These patterns may be very simple or very complicated. Complicated, for example, when a given utterance is represented upon all the fingers and thumb of a hand. But the limit of complexity is not found within these boundaries. For not even a vowel quality is represented by the activity of one unit alone upon its corresponding finger. The fundamental and an overtone are represented. The fundamental is felt distinctly, the overtone more faintly. Together they very often make a recognizable pattern.

VI.

Now I shall venture a prophecy in my own country. The use of the tactual sense and the sense of vibration by the method I am developing may yet be an independent avenue for the reception of speech by the deaf. We need to assume only that "listeners" through the skin may be equipped for teletactile audition not during only a half hour daily, but throughout the successive days of school terms.

Apart from this the method, as a supplement to lip-reading, will speed up the processes of instruction and learning generally in schools for the deaf. It will greatly facilitate the process of developing speech amongst mutes and semi-mutes. It will provide a new tool for our use in studying the psychological problems of integration in language development. It will contribute very interestingly to the psychology of meaning and of sensation. Its usefulness will be limited only when, if ever, it is appropriated and made the exclusive property of doctrinaires.

Only the first of these forecasts. I have already stated that we have talked to the skin of our subjects until two of them have been able to pick up new connected discourse by this means independently of hearing. Six times we have demonstrated that the feel of speech added to seeing it through the eyes of a lip-reader as much as doubles one's capacity to interpret what is being said. We have shown that by dint of repeatedly feeling connected speech one becomes acquainted with rhythm, varying tempo, emphasis, accent, pitch and pattern—all of which together carry meanings to you and me. Through these ways and by-ways the deaf find great aid in the reception of speech.

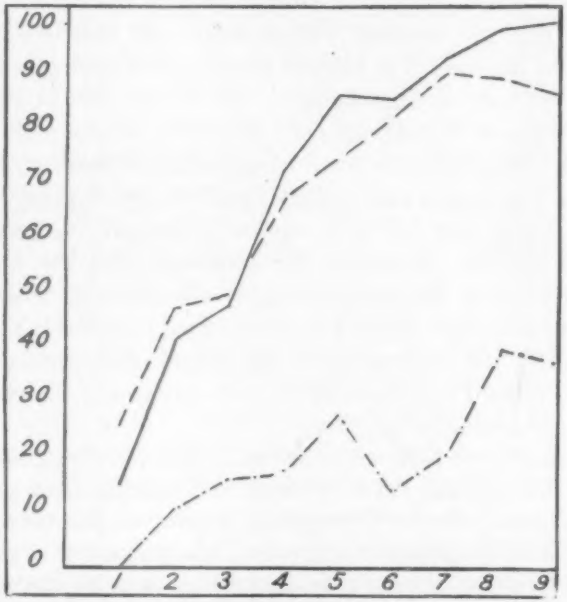
Beyond this they get a new grip upon their own vocal expression both as to enunciation and the lilt of speech. They improve themselves in the art of silent reading. And along with all this and upon a par value with it all comes increased enjoyment of speech.

The limits of this enterprise are determined wholly by the number of criteria of speech that are available through the sense of touch. By this gateway one can obtain more signs of the meanings of speech than can be got by observing the face of a speaker. This statement I make without hesitation.

I have already shown that vowel and diphthongal qualities

which carry the energy of speech can be learned by touch. I have reported also upon a preliminary experiment on the tactual identification of consonantal qualities following the long vowel *e*. The signs are convincing in this relation. Combinations of consonants with a long vowel like *e* can be tactually identified. But I am inclined to think that we are disposed to exaggerate the importance of consonants even in hearing speech, not to speak of feeling

FIG. 8.



Learning curves showing the progress of three subjects in learning 120 sentences by their tactual patterns. Figures in horizontal line indicate successive laboratory sessions. The two highest curves represent subjects who had had an aggregate of approximately 250 hours of laboratory practice. The subject who made the lowest curve had had approximately sixty hours of practice.

it. As a matter of fact, the two cases who, last May, were able to pick up a story from its feel through a single element receiver had had no systematic training on the consonants. Casually they picked up what was sufficient. The feel of intervals and stops had got into their bones, so to speak, and these sufficed as signs of consonants.

They had become saturated with the patterns of sentences and of phrases. They had learned that from a third to one-half

of colloquial sentences are concluded by prepositional phrases and the patterns of such phrases they are able to absorb.

Other tricks of their trade had been brought to their attention through scores of examples. For illustration, the word *you* is easily recognized by trained subjects. Whenever it is spotted as the third word in a sentence they know at once that it is immediately preceded by one of a few such words as *can, do, will, have, did* and *are*. They know that the first word is such as *how, why, when, where* or *what*. They know that the fourth word is a verb and that the sentence is a question. All that is a good deal to know at the start. It affords them a good spring-board from which to dive at some meanings. The recognition in addition of a few vowels or diphthongs here and there is extremely likely to bring the whole sentence train in on schedule time.

These few details may suggest, even though vaguely, how sentence patterns may be built up in a receptive organism, and psychologists will appreciate the statement that the reaction to such patterns may become thoroughly automatized, as they are in relation to hearing. From my own limited personal experience as a subject in the laboratory I can testify that automatizations similar to those I now have in mind do occur and that they occur early in the course of practice.

As a matter of fact, when one talks about building up sentence patterns through the sense of touch and making them automatic, one is talking of the very thing that is going on in every normally equipped little toddler in our homes. The youngster is getting his patterns, however, through his ears rather than his fingers. That is the only difference. He is becoming ear-minded instead of finger-minded. But if my finger-mindedness can tell me as unerringly as my ear-mindedness can that I have burned out a crank-shaft-bearing, I have, so far, no occasion for quarreling with my fingers. There is nothing sacred about signs. As the psychologist (and every other one of us) sees words, they are so many signs of meanings. "Wie befinden Sie sich?" will do as well as "How do you do?" The feel of a piece of silk may tell you as much as a paragraph can do. I care less for a sign than for its meaning.

In numerous discussions concerning this experimental enterprise considerable stress had been laid upon the extreme niceness

with which the ear can make discriminations amongst the simpler sounds of spoken language and of music. In these connections the grave question has been raised: "Can the skin begin to approximate the ear in adjustment to refined differences amongst intensities and tonal pitches? Consider the frequencies of tonal vibration that occur when only the vowel qualities are uttered! For the male voice scattered frequencies run up to the height of 3800 a second and for the female voice to 4800." [2]

Very well then, as to intensities: Discriminating by feel amongst intensities of vibration against the skin. In this case the organs of touch can do as delicate a piece of work as the ear. If by ear one can make 100 distinctions of loudness between a higher and a lower limit, so can one by touch. I make this statement on the authority of Dr. V. O. Knudsen, whose unpublished paper has already been referred to.

But what about frequencies of vibration that correspond to the pitches of tones? Here the skin lags behind. Doctor Knudsen did not find that the skin can sense a higher rate of vibration than 1600 d.v. a second. The highest figure that has ever been published in this connection is 1552, and that by Landlois in his "Lehrbuch d. Physiologie d. Menschen," 1880. But 1600 is too low. For on the ninth, tenth and eleventh of March, 1927, I succeeded in proving that each one of three deaf subjects on whom the test has been made can by touch sense vibrations of 2000 d.v. or above. I have already explained that the fifth post or button on the teletactor vibrates with the reed to which it is attached *only* in frequencies of 2000 d.v. or more. In more than 80 per cent. of cases they sense a vibration when long *e* (German *i*) is pronounced. It is not only an initial surge of the vibrating unit that is felt, but a continuous vibration when long *e* is drawn out. In approximately one-half of instances they catch a vibration of the same post when *er, ah* and *aw* are pronounced. Very soon, I think, we shall be able to determine just how far above 2000 d.v. they can go. I ought to say here that the stimulus was habitually received by hooking a finger-nail solidly over the post. But the vibration can, nevertheless, be got against the skin directly.

[2] Crandall, *op. cit.*

According to Crandall's figures the frequencies above 2000 that occur in relation to these vowel qualities are as follows:

ee	2987
er	3050
aw	3612
ah	3683

The above qualities were sensed through the 2000 plus reed, more or less frequently by all subjects. Our generally most successful deaf case, on the other hand, never sensed *o* and *oo*. According to Crandall, once more, these qualities have frequencies above 2000 as follows:

o	3475
oo	3700

Observe that our subjects are most successful in detecting *e* on the 2000 plus reed. Its high frequency is but little under 3000 d.v. on the basis of Crandall's table. Other investigators have reported frequencies above 2000 for long *e* as follows: Donders (1870), 2816; Helmholtz (1863), 2304; König (1870), 3760; Miller (1916), 3100; Modell and Rich (1915), 3744; Köhler (1909), 3480.[3]

So much for the upper limit of tactual sensitivity for frequencies. The lower limit is as low as that for hearing.

These data in themselves offer great encouragement in this research. For the frequencies that are essential to the under-

[3] Since this paper was written and read we have used an oscillator through a single unit of the teletactor system at a time to determine the highest frequency that can be detected tactually. At each of several frequency stages from 150 d.v. to 2600 d.v. inclusive we have found the threshold for the sense of touch and have recorded the corresponding dial settings. Subsequently we have repeated these settings, and with a depth-gauge have measured the displacement of the vibrating element at each successive stage. These measurements afford the data for a "tactogram." Below (Fig. 9) are two such "tactograms" based on introspections by the author. These are based upon two series of observations: One was made when the stimuli were received against the end of the nail (left index) against the vibrator, the other when the stimuli were upon the skin near the tip of the same finger. Another subject, who received the stimulus only against the nail of the small left finger reached to the frequency of 2700 d.v. The thresholds for these two observers are not widely different. The hump in the curves is near the region of resonance of the vibrating reeds.

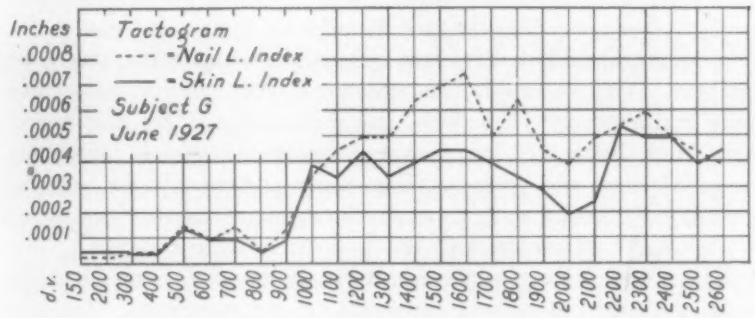
Our next step in this connection is to measure the displacement of the vibrating element *while the finger is in contact with it* by means of a microscope equipped with a micrometer eye-piece.

standing of speech by ear lie far below the uppermost of these limits.

Apart from all this is the question: What is the degree of refinement with which the organs of touch can discriminate differences of vibrational frequency? Doctor Knudsen, in the work already referred to, says that the rate of vibration must change by as much as 15 per cent. to 30 per cent. before a difference can be noticed tactually. How much more refined is the ear that can pick up differences of three-tenths of one per cent.!

Our preliminary results, on the other hand, prove that differences of 9 per cent. can be sensed. This applies only as far as

FIG. 9.



we have gone to the present; that is, up to 600 d.v. The stimulus was applied to the ball of the thumb through the single-unit receiver with a diaphragm, which has already been described. Through the courtesy of the Bell Telephone Laboratories we are able to use an oscillator in connection with this phase of our work. By means of a depth gauge we have determined that the displacement of the vibrating diaphragm over the range we have covered is 0.001 inch with practically no variation. It yet remains to be seen what can be done in this direction by means of the new teletactor.

These results are of more than ordinary scientific interest, I am sure, falling as they do upon the frontier of a pioneer state. Truly we are not yet aware of the utmost limits of the capacity of the human organism to adapt itself to external stimulation. I have already suggested that we have by no means sent a plumb line to the bottom of the possibility of substituting one organic function for another.

Running again to the practical aspects of this enterprise: To the question how far we can go through the senses of touch and vibration toward developing a language sense in its several implications. We must forget a deal about the hearing of speech. We are biased toward our whole mountains of data relating to the physics and physiology of hearing. Our practical question is not whether through the skin we can distinguish frequency differences amounting to one-third of one per cent. as we can by ear, and whether we can sense frequencies running up to ten, twenty or thirty thousand vibrations a second. The real question is: "Can we get enough criteria through the old gates in the skin?" Well, the energy of speech is carried by frequencies below 1200 d.v. for a certainty. We can make out more differences of frequency than Doctor Knudsen's figures indicate. The feels of vowel and diphthongal qualities are separated one from another. We can repeat this statement with relation to at least many combinations of vowels and consonants. We can distinguish time intervals, the changing tempo of speech, emphasis, accent, rhythm and pattern. Can we put these criteria together in enough different ways to make up as many signs of meanings as we require to understand the lost art of conversation?

If we have but ten apples in a row we can shift them about till we have counted more than three million arrangements.

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AN X-RAY STUDY OF THE BETA TRANSFORMATION IN COPPER-ZINC ALLOYS.

BY

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SINCE 1911 many investigations have been undertaken with the purpose of determining the exact temperatures at which brasses containing the beta solid solution show a marked thermal effect when heated or cooled through a temperature range extending from 450° to 500° C. Although the temperatures of the transformation seem to have been fairly well determined, as yet no generally accepted explanation of the physical changes accompanying the thermal effect has been offered.

The first record of the transformation appeared in a paper by Roberts-Austen [1] in which he pointed to an arrest at 450°–470° C. in thermal curves of brasses containing 45–75 per cent. copper. Shepherd [2] and Tafel,[3] a few years later, failed to find the thermal effect, although they apparently made careful attempts to verify Roberts-Austen's work. In 1911, Carpenter and Edwards [4] proved without question the presence of the transformation point and attributed it to an eutectoid inversion of beta into alpha plus gamma. In two later papers Carpenter offered photographic evidence which seemed to prove his contention that beta brass below 470° C. consists of alpha and gamma associated in a state of division just within the resolving power of the microscope.

In 1914 Hudson [5] rejected Carpenter's interpretation in favor of an explanation based on a polymorphic transformation of beta

[1] W. Roberts-Austen, "Fourth Report of the Alloys Research Committee," *Proc. Inst. Mech. Eng.* (1897).

[2] E. S. Shepherd, "The Constitution of the Copper-Zinc Alloys," *Jour. Phys. Chem.*, **8** (1904).

[3] V. E. Tafel, *Metallurgie*, **5** (1908).

[4] H. C. H. Carpenter and C. Edwards, "A New Critical Point in Copper-Zinc Alloys," *Jour. Inst. Metals*, **5** (1911).

[5] O. F. Hudson, "The Critical Point of 460° C. in Zinc-Copper Alloys," *Jour. Inst. Metals*, **12** (1914).

into a beta modification which could not be distinguished from beta by microscopic examination. His reasons for this stand were (1) that he was unable by annealing at temperatures under the critical temperature to obtain satisfactory evidence of a duplex structure and (2) that he was able to produce beta synthetically from alpha and gamma at temperatures well below the transformation temperature. As a result of Hudson's experiments the polymorphic transformation theory was tentatively accepted and Carpenter's photographic evidence was considered to have been based on misleading etching effects frequently disclosed at high magnifications.

Recently, further interest has been manifested in the location of the transition point. In 1922 Imai [6] and Matsuda,[7] by means of thermal expansion and electric resistivity measurements, have determined the transition temperatures for brasses containing 60.92 to 41.37 per cent. copper. According to their results, an alloy containing beta when heated shows a steady and almost linear increase in expansion or resistivity until a temperature ranging from 300°–350° C. is reached, where a fairly rapid increase takes place up to 480° C., after which the rate of change becomes less and the curve again becomes almost linear. The second part of the curve (extending from about 300°–480° C.) is referred to by the authors as a progressive transformation and the end of the transformation (480° C.) is called the critical temperature. Matsuda, furthermore, by thermal analysis places the loci of the critical points as a horizontal line at 480° C. This temperature is obtained by taking the mean values of the temperatures of the beginning and ending of the transformation range on cooling and heating.

In 1925, Gayler [8] and Haughton and Griffiths,[9] by thermal analysis and electric resistivity methods, respectively, obtained excellent agreement in respect to transformation temperatures. Their results (Fig. 1) show a horizontal line traversing the

[6] H. Imai, "On the Equilibrium Diagram of the Copper-Zinc System," *Science Reports*, Tôhoku Imp. Univ., 1st Series, 11 (1922).

[7] T. Matsuda, "On the Transformation in Bronze, Aluminum-Bronze and Brass," *Science Reports*, Tôhoku Imp. Univ., 1st Series, 11 (1922).

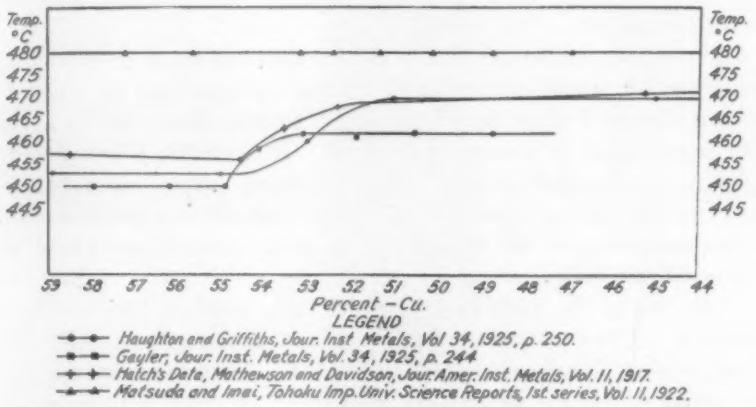
[8] M. Gayler, "On the Constitution of Zinc-Copper Alloys Containing 45 to 65 Per Cent. of Copper," *Jour. Inst. Metals*, 34 (1925).

[9] I. Haughton and W. Griffiths, "The Beta Transformation in Copper-Zinc Alloys," *Jour. Inst. Metals*, 34 (1925).

alpha-beta field at 450° C., followed by a curve rising to approximately 470° C. at the boundary line between the beta plus gamma field. It is interesting to note the agreement of their results with the data of Hatch reported by Mathewson and Davidson [10] in 1917.

In reviewing data obtained by thermal analysis with the object of locating the exact temperature of solubility or phase change, one is invariably confronted with apparent discrepancies resulting principally from inconsistent interpretations of cooling curves.

FIG. 1.


Temp. °C
480
475
470
465
460
455
450
445
59 58 57 56 55 54 53 52 51 50 49 48 47 46 45 44
Percent – Cu.
LEGEND
Haughton and Griffiths, Jour. Inst. Metals, Vol 34, 1925, p. 250.
Gayler, Jour. Inst. Metals, Vol. 34, 1925, p. 244
Hatch's Data, Mathewson and Davidson, Jour. Amer. Inst. Metals, Vol. 11, 1917.
Matsuda and Imai, Tohoku Imp. Univ. Science Reports, 1st series, Vol. 11, 1922.

Some investigators choose the beginning of a cooling effect, others the end, and still others the temperature of maximum effect. Other complications arise due to varying rates of cooling or heating, supercooling, etc., all of which render difficult a harmonious comparison of several works. From the wealth of experimental data which has been accumulated relative to the temperatures of the beta transformation, it seems evident that the change is at constant temperature (450° C.) through the alpha-beta field, but takes place at progressively higher temperatures through the beta field.

Turning now to the question of the significance of the transformation or critical point, we have referred to the two earliest explanations, namely, Carpenter's eutectoid theory and Hudson's polymorphic transformation theory. More recently Matsuda and

[10] C. H. Mathewson and P. Davidson, "Metallography of Brass," *Jour. Amer. Inst. Metals*, 11 (1917).

Imai have stated their belief that no change of phase is involved but that it consists of a change in atomic energy, analogous to Honda's interpretation of the A_2 transformation in iron.

It seemed to the present authors that X-ray analysis should be capable of yielding conclusive evidence regarding the nature of the transformation if a phase change takes place, whether it be an eutectoid inversion or a polymorphic transformation. It has been shown that microscopic examination of beta brasses quenched from temperatures above the critical point has failed to solve the question. Thermal analysis, although showing unquestionably a marked thermal effect, gives no clue to the character of the transformation.

For these reasons, it would appear that the most enlightening information would result from a direct comparison of spectrograms obtained from beta brass when heated above 480° C. and the same brass at room temperature. Rosenhain, Johnson, and Gayler, in the discussion of Gayler's paper, stress the necessity of making X-ray studies above the critical temperature and draw attention to the danger of forming conclusions based on observations on quenched alloys.

As far as the authors are aware, this method had not been utilized in this connection by previous investigators with the exception of Imai, who stated that "no differences in the distribution of Laue's spots were observed" in brass containing 48 per cent. copper when heated to temperatures well above the critical temperature. The Laue photograms shown by Imai, however, could hardly be considered conclusive proof of this statement.

The lattice of beta brass has been studied by several investigators, notably Andrews,[11] Owen and Preston,[12] and Westgren and Phragmén.[13] Miss Andrews erroneously reported that brasses containing 37–53 per cent. copper are body-centred. Owen and Preston, working with brass containing 51.5 per cent. copper, assign to beta brass a body-centred lattice with a lattice constant d_{100} 2.946 Å. A specimen of this composition quenched

[11] Mary Andrews, "X-ray Analysis of Three Series of Alloys," *Phys. Rev.*, **18** (1921).

[12] E. A. Owen and G. D. Preston, "X-ray Analysis of Zinc-Copper Alloys," *Proc. Phys. Soc. London*, **36** (1923–1924).

[13] Westgren and Phragmén, "X-ray Analysis of Copper-Zinc, Silver-Zinc, and Gold-Zinc Alloys," *Phil. Mag.*, **1** (1925).

FIG. 2.

Beta brass—Copper 50.4 per cent.

from 550° C. gave essentially the same refractions as one annealed well under 470° C. Their results are in good agreement with Westgren and Phragmén's value of d_{100} 2.945 Å. for brass containing 53.1 per cent. copper.

Before attempting to determine the lattice characteristics of beta brass above the transformation range, it was deemed advisable to obtain spectrograms at room temperature of the beta brass to be used in subsequent high-temperature studies. In order to

TABLE I.

Diffraction Data (Room Temperature), Beta Brasses.

Powdered Material through 240-mesh Screen. Mounted on Thread in Collodion.					24-hour Exposure. 24 Milliamperes. 90 Volts.	
	50.4 Cu.		51.1 Cu.		51.2 Cu.	
Miller Indices.	Observed Spacings.	Cube Edge.	Observed Spacings.	Cube Edge.	Observed Spacings.	Cube Edge.
	Å.U.	Å.U.	Å.U.	Å.U.	Å.U.	Å.U.
110	2.125	3.005	2.100	2.970	2.100	2.970
100	1.490	2.980	1.479	2.958	1.475	2.950
211	1.214	2.975	1.206	2.955	1.206	2.955
110 (n–2)	1.050	2.966	1.045	2.951	1.045	2.951
310	.936	2.962	.931	2.946	.937	2.965
111	.856	2.967	.854	2.960	.854	2.960
321	.792	2.964	.790	2.956	.791	2.960
Mean values, a_0		2.974		2.956		2.958

Type of lattice—body-centred cubic.

ensure equilibrium condition of the beta, samples containing 50.4, 51.1, and 51.2 per cent. copper were annealed for forty hours at 440°–445° C. and furnace cooled. After the outer surface was removed and discarded, filings were obtained by means of a 10″ mill-cut file. The filings which passed through a 240-mesh screen were then mounted on a cotton thread moistened with collodion. The X-ray equipment used was the standard X-ray Diffraction Apparatus made by the General Electric Company. For calibration purposes, preliminary tests were made on pure copper of known lattice dimensions.

The diffraction data are assembled in Table I. A representative spectrogram is shown in Fig. 2. Unfortunately, it is impossible to reproduce the lines of the film on print paper without great sacrifice of detail. Calculations based on the diffraction lines observed for the 50.4, 51.1, and 51.2 per cent. copper alloys

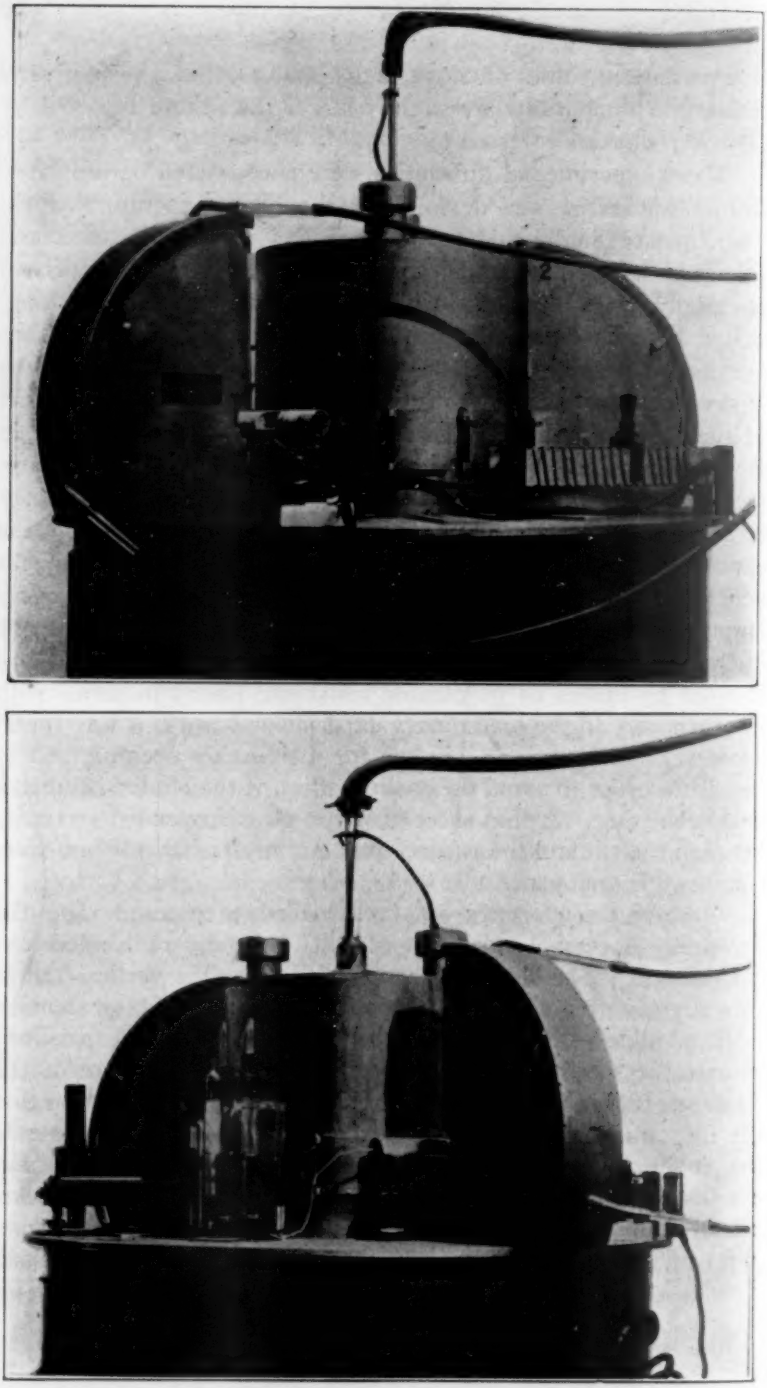
give parameter values of 2.974, 2.956 and 2.958 Å., respectively. These unit dimensions are slightly larger than those reported by the other workers referred to.

Many experimental difficulties were encountered before satisfactory apparatus was devised for the high-temperature work. The furnace finally adopted was similar to the one used and described by Peirce, Anderson and Van Dyck.[14] It consisted essentially of an alundum tube 7/8″ inside diameter and 6″ long, heated by nichrome coils embedded in alundum cement. Two rectangular openings were cut through the tube, which allowed the X-ray beam to pass through the furnace without striking any part of the tube or cement. Silica tubes of small bore were set in the alundum cement in the centre of each end of the furnace, thereby furnishing supports for the specimen tube and also for the thermocouple introduced at frequent intervals during the exposure. The furnace was supported by two adjustable jacks which permitted considerable vertical movement for properly aligning the furnace openings with respect to the slit of the diffraction apparatus. Convenient temperature control was effected by means of an outside resistance placed in series with the furnace. In the preliminary experimental work, it was found necessary to improvise a window for the furnace opening next to the slit in order to avoid the cooling effect of the blower operating within the case. A thin sheet of pyrex glass suspended vertically between the slit and the furnace was entirely satisfactory in overcoming this annoyance.

One of the cassettes was remodelled to accommodate the furnace. A semi-circular slot of 9/16″ radius was milled into the cassette. The slot was then filed so that the vertical radius was slightly greater than the horizontal radius. This extension made possible a slight vertical adjustment of the furnace necessary in case the specimen was not located in the exact centre of the furnace. It was found during our first high-temperature test that the film was heated to an excessively high temperature due to the conduction of heat from the furnace. This trouble was eliminated by circulating cold water through a rubber jacket placed between the film and the back of the cassette. The several parts of the apparatus used are shown in Fig. 3. Several blank

[14] Peirce, Anderson and Van Dyck, JOUR. FRANK. INST., September, 1925.

FIG. 3.



tests were necessary before an assembly was perfected which did not yield extraneous lines.

Brass powder, containing 51.1 per cent. copper, was screened through a 240-mesh screen and tapped into a thin wall pyrex glass tube, 1/64″–1/32″ outside diameter, and approximately 5″ long. One end of the tube was sealed and the other end closed by a plug of asbestos wool. In order to avoid serious changes in chemical composition during the exposure, fresh speci-

TABLE II.

Diffraction Data at 520° C., Beta Brass (51.1 Cu).

Material Powdered to Pass through 240-mesh Screen. Mounted in Pyrex Tubes.		20-hour Exposure. 24.1 M.A. 89.9 Volts. Aver. Temp., 520° C.
Miller Indices.	Observed Spacings.	Calculation of Cube Edge.
	Å.U.	Å.U.
110	2.150	3.041
100	1.510	3.020
211	1.230	3.014
110	1.063	3.002
310	.947	2.996
111	.860	2.981
321	.800	2.994
		Aver. 3.007

Type of lattice—body-centred cube.
Mean value a_0—3.007 Å.U.

mens were inserted every two hours of the 20-hour exposure. Opportunity was taken at this time to measure the temperature of the furnace at the exact location of the specimen tubes. No difficulty was experienced in maintaining suitable temperature control. The average temperature based on eleven readings was 520° C.

The diffraction data are summarized in Table II. Although the lines were clearly shown on the film, they were not strong enough to be reproduced on print paper. Undoubtedly the use of the glass tube and the glass window of the furnace greatly reduced the intensity of the diffraction pattern. Excellent agreement was obtained in three spectrograms resulting from the high-temperature experiments. Calculations based on the diffraction lines show that beta brass at 520° C., well above the transformation range, is body-centred with a lattice constant d_{100} 3.007 Å.

This unit dimension represents an increase in length of 1.72 per cent. over the cube edge of the same brass at room temperature.

On the basis of X-ray evidence, it may be assumed that the 470° C. transformation of beta is not due to an eutectoid inversion. Moreover, it does not signify a polymorphic transformation, if by polymorphism we demand that the two, or more, forms have different atomic arrangements. If, on the other hand, we accept Sauveur's [15] broader interpretation that polymorphism may be manifested by a spontaneous evolution, or absorption, of heat without an accompanying lattice change, the beta transition may be considered of a polymorphic nature. In other words, it may be associated with an energy change without any fundamental alteration of the crystalline lattice.

Rosenhain [16] suggests that the beta and gamma solutions of the copper-zinc system are based upon an allotropic lattice of copper. As far as the present writers are aware it has never been demonstrated that copper has allotropic forms. With regard to zinc, the X-ray studies of Peirce, Anderson and Van Dyck (*l. c.*) show that there is no allotropic transformation between 20° and 400° C.

If we accept the explanation offered by Matsuda and Imai that the change is due to a marked energy change within the atom, it is reasonable to assume that the energy change is confined to one of the participating atoms, *i.e.*, either copper or zinc atoms. It is rather improbable that such a change takes place within both the copper and zinc atoms at approximately the same temperature. If this assumption is correct, the magnitude of the thermal, or other effects, concomitant with the transformation, should change with the atomic concentration of the beta solution. Unfortunately, the several effects have not been measured with sufficient accuracy to establish this point.

Conclusions based on experimental results:

(1) The lattice of beta brass is body-centred. The lattice parameter increases with the zinc content. Beta brasses containing 51.1 per cent. and 50.4 per cent. copper have lattice constants d_{100} 2.956 Å. and d_{100} 2.974 Å., respectively.

(2) Beta brass above the transformation temperature (or range) is also body-centred. At 520° C., its parameter is 3.007 Å.

[15] Sauveur, *Jour. Iron and Steel Inst.* (1913), No. 2.

[16] Rosenhain, May Lecture, *Jour. Inst. Metals*, **30** (1923).

SENSITIVITIES OF DETONATING COMPOUNDS TO FRICTIONAL IMPACT, IMPACT, AND HEAT.

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AT THE suggestion of Dr. C. E. Munroe, Chairman of the Committee on Explosives of the National Research Council, a study of the sensitivities of a large number of initiating compounds was undertaken. This was carried out with particular attention to the effect of frictional impact upon these substances; the values for sensitivity to impact and to heat being determined in an effort to find, if possible, a correlation between the three types of physical influence.

Many isolated data on the sensitivities of a limited number of detonating compounds are found in the literature, but the apparatus used and the procedure followed by the different investigators were not similar in all cases, and it is not possible to establish tables of comparative values from their results. With this in mind, the apparatus used and procedures followed in this study were improved and standardized as much as possible and are described in detail. These were as follows:

APPARATUS FOR SENSITIVITY TO FRICTIONAL IMPACT.

For determining the sensitivity to frictional impact (glancing blow), a small pendulum friction machine was used. This was constructed on a scale one-fourth that of the large machine described by Hall and Howell.[1] The shoe and impact block were of soft steel; the impact block was slightly concave and its central portion was transversely scored to prevent the light, crystalline materials being swept away. The rest of this apparatus was constructed of brass. The shoe weighed 74 grams and the rod connecting the shoe to the axis was 50 cm. long and weighed 310 grams.

[1] *U. S. Bureau of Mines Bulletin 66*, pp. 15–16.

Weights amounting to 4.35 kgs. could be added to the shoe, and the impact block could be adjusted to give any desired degree of friction. Such an adjustment, that the shoe would pass over the impact block ten to twelve times when no explosive was on the block and when a weight of 0.2 kg. was added to the shoe, was adopted as standard. A small quantity of the explosive was pressed on the scored portion of the block, and the shoe (with or without added weights) was dropped through a vertical distance of 12.5, 25, 33, 37.5, or 50 cm. and allowed to rub back and forth over the material. The number of swings made before the shoe came to rest was noted, and also the particular passage on which explosion took place. Most of the sample was swept off during the test. If no explosion resulted, more of the explosive was placed on the block and the test repeated. The object was to find the lowest combination of weight and drop that would cause an explosion. After an explosion, at least ten tests were made with the next smaller drop or weight in order to establish the higher point as the minimum required for detonation.

APPARATUS FOR SENSITIVITY TO IMPACT.

The small impact machine was used for testing sensitivity to impact. The apparatus adopted and described [2] some years ago was modified to meet the requirements of this investigation. The original impact block of case-hardened steel on which the 0.02-gm. sample of explosive rested was somewhat deformed by only one or two explosions of an azide or fulminate, while the tip of the soft-steel plunger was battered easily, and the uneven surfaces thus produced would then cause variable values to be obtained.

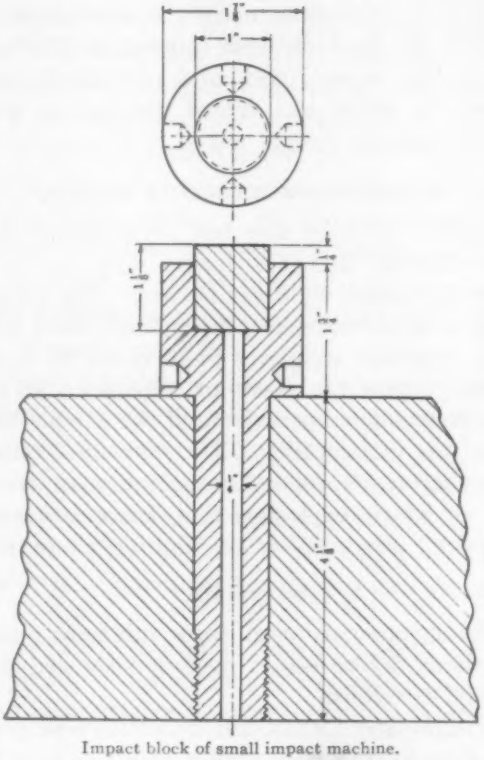
Because of this the impact block and plunger were changed so that it was possible to have uniformly smooth surfaces of hard steel for each test. Fig. 1 shows the new design of the impact block with easily replaceable middle section. Fig. 2 shows the redesigned steel plunger with hard-steel tip 1 cm. in diameter. The weight of plunger and tip was 840 grams. The impact weight or "hammer" used for delivering the impact was the same design as before but weighed only 500 grams instead of 2000, as it was found that the height of the drop did not differ

[2] *U. S. Bureau of Mines Bulletin 15*, pp. 101–103, Hall, Snelling, and Howell.

sufficiently for different explosives when the 2000-gm. weight was used.

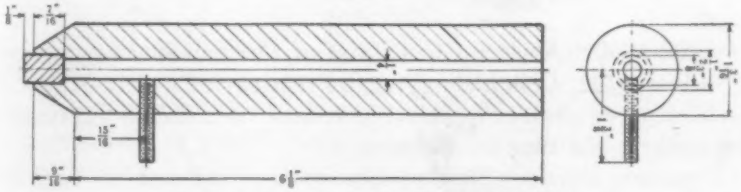
Procedure.—The 0.02-gm. sample to be tested was placed on

FIG. 1.



Impact block of small impact machine.

FIG. 2.



Plunger and plunger tip of small impact machine.

the centre of the impact block. The plunger was lowered so that the tip covered the entire layer and pressed the explosive to a compact mass. The 500-gm. impact weight was then allowed to fall

from a measured height and strike the plunger. If no explosion took place, the residue of the sample was brushed off and the weight was dropped a greater distance on a new sample. When explosion resulted, the height of fall of the weight was decreased until there was no explosion in five or more trials with a fall 1 cm. less than the least distance causing an explosion. After each explosion the impact block and plunger tip were cleaned and inspected. If either was dented, cracked or spread, it was replaced before making further tests.

APPARATUS FOR SENSITIVITY TO HEAT.

The apparatus used in this test consisted of an iron dish 4 inches in diameter and 1½ inches deep, nearly filled with Wood's alloy and heated by a gas burner. The temperature was read by means of a thermometer, the bulb of which was immersed in the alloy. Samples weighing from 0.005 to 0.05 gm. were used, depending upon the force of explosion. The bath was brought to a constant temperature and the sample dropped upon the surface of the molten alloy. The temperature and length of time elapsing before explosion took place were recorded. The temperature at which explosion took place instantaneously or within one second was taken as the ignition temperature.

MATERIALS.

All of the compounds used were carefully purified by the standard methods before use. Inspection showed their physical structures to be as follows:

Mercury fulminate: Octahedral crystals whose greatest length varied from 0.04 to 0.18 mm. with a width of 0.02 to 0.12 mm.

Silver fulminate: Colloidal aggregates about 0.15 mm. in length.

Lead azide: Appeared to consist of fine colloidal aggregates.

Silver azide: Colloidal aggregates that varied widely in size.

Mercurous azide: Appeared to consist of colloidal aggregates averaging 0.002 mm. in diameter.

Cyanuric triazide: Needles from 0.04 to 0.2 mm. in diameter and averaging 0.1 mm. in length.

Hexamethylenetriperoxidediamine: A mixture of needles and pseudo-blocks. Needles 0.03 to 0.15 mm. in length; blocks had an average diameter of about 0.05 mm.

Silver acetylide A: Colloidal aggregates forming lumps. Obtained by passing C_2H_2 into a neutral aqueous solution of $AgNO_3$. Very compact.

Silver acetylide B: Same form as A. Obtained by passing C_2H_2 into a solution of 5 gms. of $AgNO_3$ in 200 c.c. of water and 5.3 c.c. of concentrated NH_4OH solution.

Silver acetylide C: Same form as A. Obtained by passing C_2H_2 into a solution of 5 gms. of $AgNO_3$ in 200 c.c. of water and 20 c.c. of concentrated NH_4OH.

Silver acetylide D: Soft lumps made up of colloidal aggregates. Obtained by passing C_2H_2 into a solution of 5 gms. of $AgNO_3$ in 200 c.c. of water and 5 c.c. of concentrated HNO_3.

Silver acetylide E: Same form as D. Obtained by passing C_2H_2 into a solution of 5 gms. of $AgNO_3$ in 200 c.c. of water and 25 c.c. of concentrated HNO_3.

Normal lead trinitroresorcinate: Crystals from 0.04 to 0.24 and averaging 0.10 mm. in length. Probably orthorhombic with prism, micropinacoid, and brachydome faces well developed.

Silver trinitroresorcinate: Needles from 0.02 to 0.12 mm. in diameter and averaging 0.06 mm. in length.

Lead picrate: Crystals from 0.07 to 0.16 mm. in length.

Silver picrate: Slender needles as long as 1 cm. and averaging 3 mm.

Barium picrate: Needles as long as 1 inch.

Copper picrate: Needles from 0.015 to 0.11 mm. in length.

Mannitol hexanitrate: Needles as long as 3 mm. and averaging 1.0 mm.

Dulcitol hexanitrate: Thick needles as long as 3 mm. and 0.8 mm. thick. Average about 1 mm. long.

Potassium chlorate: C. P. material ground to pass 200-mesh screen.

These purified materials were placed in sulphuric acid desiccators and kept in a dark place for several weeks before use in the tests, small quantities being removed when needed. As none of the compounds listed is more than very slightly hygroscopic on lengthy exposure to moist air, the short exposure to the atmosphere involved in this procedure could not cause variation in values as a result of the absorption of moisture. Room tempera-

tures when the experiments were made were always between 22° and 28° C. This slight variation in temperature of the apparatus and material being tested should have but slight effect upon the results obtained.

While standardization to the extent of so grading and separating the individual particles of each compound that one size of all or a fixed size of each would have been desirable, inspection of the dimensions found show the difficulty of obtaining this result. Furthermore, the samples used are representative of the size variations and physical forms in which these compounds are obtained by standard methods and used in practical applications.

RESULTS.

The results obtained by the tests are given in Table I.

TABLE I.

	Pendulum Friction.			Impact Fall (cm.).	Explosion Temp., °C.
	Added Wt. (kg.).	Fall (cm.).	Swings, No.		
Silver acetylide (C)	0.0	12.5	2	66	171
Cyanuric triazide	0.0	12.5	3	7	252
Mercury fulminate...90 $KClO_3$...10	0.0	25	3–4	23	240
Mercury fulminate...80 $KClO_3$...20	0.0	25	3–5	19	235
Mercury fulminate	0.0	25	3–10	24	260
Silver fulminate	0.0	25	10	38	245
Silver acetylide (B)	0.0	33	4	15	177
Silver trinitroresorcinate	0.0	33	7	28	305
H. M. T. D	0.2	37.5	5–7	8	200
Silver acetylide (D)	0.2	50	8	79	200
Lead azide	0.45	37.5	12	43	383
Dulcitol hexanitrate	1	25	14	47	205
Silver acetylide (A)	1	33	12	43	225
Mercurous azide	1	50	16–17	6	298
Lead picrate	1	50	23–37	4	281
Lead trinitroresorcinate	1	50	29–37	50	293
Silver acetylide (F)	2	50	16	64	200
Silver azide	4.35	33	39	41	273
Silver picrate	>4.35	50	27–38	34	335
Barium picrate	>4.35	50	33–36	>110	403
Copper picrate	>4.35	50	34–40	>110	373
Mannitol hexanitrate	>4.35	50	49–54	24	232

The results were obtained under comparable conditions. Lead picrate exploded by the drop of the weight through 4 cm. after the plunger had been pressed firmly on it, but it required a fall of 36 cm. when placed loosely on the block and not compressed by more than the weight of the plunger. The large matted crystals of silver picrate did not explode when the weight was dropped 110 cm., but when pulverized, a drop of only 34 cm. was sufficient to cause explosion.

The following results show the necessity of having smooth surfaces of steel of constant hardness for the impact block and plunger tip:

Explosive.	Smooth, Hard Steel, cm.	Ordinary Smooth Steel, cm.	Hard Steel, Roughened by Use, cm.
Mercury fulminate	24	53	15–75
Silver picrate	34	80	19–90
Mercurous azide	6	6	4–12
Silver trinitroresorcinate	50	80	13–65

The steel for each new set of blocks should be tested with mercury fulminate or some other compound that will give uniform results to see that the results agree with those previously obtained.

The plate and shoe on the pendulum friction apparatus must also remain constant in composition and hardness, and the scoring in the block should be kept the same. The results in this test are comparative and some compound should be used as a standard of comparison.

The results obtained by the heat test can be duplicated easily. Check results were obtained by dropping the material on a hot metal bar, the temperature of which was read by a thermocouple soldered in near to the explosive. These checked those obtained by the regular method within one or two degrees. Attempts were made to plunge the sample below the surface of the molten metal in the regular method, but the results were unsatisfactory; it being impossible to obtain ignition temperatures uniformly lower than those obtained by dropping the material on the surface.

Consideration of the results given in the table indicates that there does not exist a direct relationship between the values for different substances by any one test. However, if we divide the

materials into classes on the basis of the frictional impact test and then average the results obtained by the impact and heat tests for the materials in each class, averages indicating a general correlation are obtained. This is as follows:

Friction Impact, Carrying Added Weight.	Impact Test, Average Minimum Fall, cm.	Heat Test, Average Ignition Temp., °C.
0.0 kg.	27.5	235
0.1 to 3.0 kg.	38	254
4.35 kg.	>64	325

This may be taken to indicate that, in a general way, sensitivity is not specific toward any one form of physical influence.

SUMMARY.

Using standardized tests, the sensitivities of twenty compounds and two mixtures to frictional impact, impact, and heat have been studied and recorded. The results show that values obtained by one test are not paralleled by those of either of the other two tests, but that, on division into classes, averages indicating a general correlation are obtained.

ACKNOWLEDGMENTS.

The authors gratefully acknowledge the suggestions and assistance of Mr. J. A. Rowe in the design and construction of the apparatus used in this work.

MATHEMATICAL METHODS OF FREQUENCY ANALYSIS OF SIZE OF PARTICLES.*

PART II. APPLICATION TO SILVER BROMIDE PRECIPITATES.

BY

R. P. LOVELAND and A. P. H. TRIVELLI.

IN THE first paper [1] a method of size-frequency analysis was presented and it was remarked that in the analytical study of a series of dispersed particle systems, simple graphical methods may be highly efficient and all that is necessary, for certain purposes. This was well illustrated by data from a group of silver bromide precipitates in gelatin obtained by Dr. R. H. Lambert of these laboratories.

Detailed description of the methods used in their preparation will be furnished in another paper from this laboratory. For our purpose, *i.e.*, to show that these particular graphical methods are especially capable of simplifying the apparent size-frequency distribution, disclosing any regularities and indicating their nature, it is sufficient to state that thirty-three precipitates were obtained which varied from each other only in two carefully controlled factors so that four separate series could be formed which varied in themselves only in one factor. Size-frequency determinations were then made in the usual manner,[2] using, in each case, the same concentrations of silver bromide per unit area of single layer plate. The number of grains measured averaged 3720 per final curve, which in each case was a mean of three separate determinations.

DOUBLE LOG ANALYSIS OF PRECIPITATION DATA.

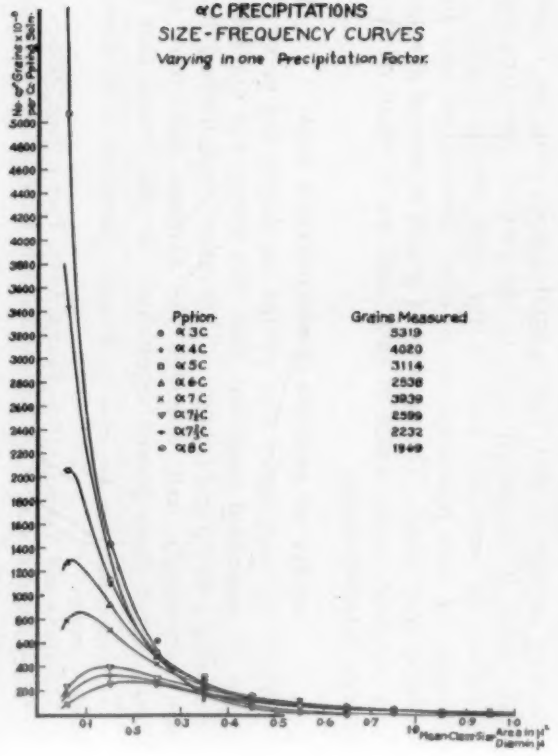
When one such series was plotted on double log paper the graphs so resembled parabolas that this curve was applied to them using a string and triangle. This rather crude method fitted them surprisingly well, although the extreme tails were not plotted, which later proved significant. It was found that by

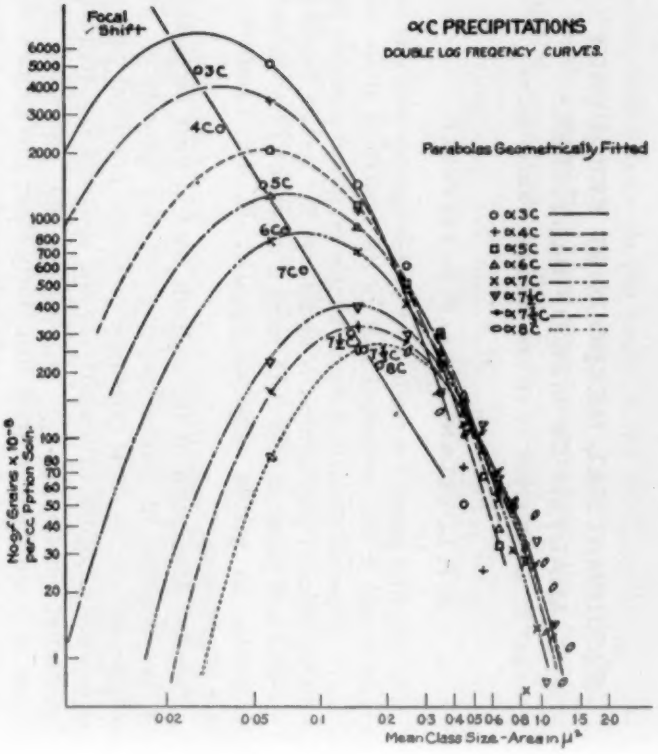
* Communication No. 300 from the Research Laboratory of the Eastman Kodak Company.

[1] LOVELAND and TRIVELLI, JOUR. FRANK. INST., Part I, Aug., 1927.

[2] E. P. WIGHTMAN, A. P. H. TRIVELLI, and S. E. SHEPPARD, *J. Phys. Chem.*, 27, 1 (1923).

FIG. 1.


αC PRECIPITATIONS
SIZE-FREQUENCY CURVES
Varying in one Precipitation Factor.
Pption
Grains Measured
α 3C 5319
α 4C 4020
α 5C 3114
α 6C 2538
α 7C 3939
α 7½C 2599
α 7¾C 2232
α 8C 1949
Mean Class Size - Area in μ²


Focal Shift
αC PRECIPITATIONS
DOUBLE LOG FREQENCY CURVES.
Parabolas Geometrically Fitted
3C
4C
5C
6C
7C
Mean Class Size - Area in μ²

shifting the separate sheets of paper, one behind the other, these graphs could be almost exactly superimposed with the directrices forming one straight line and the foci lying within a centimetre circle of a common point. Moreover, when plotted on one paper, the foci of the curves lay on a straight line. That means that the double logged size-frequency distribution was unchanged in shape by this factor but merely shifted linearly. As the grain size increased, more and more of the distribution curve seems to come out from behind the curtain of limiting resolution and lay along the general curve which may further justify extrapolation to complete the first class width as mentioned in the first paper (p. 197). All of the data in all of the series was fitted by the same curve which is *not,* however, a simple parabola but *is* unaffected by the precipitation factor within the limits of error. Certainly no such simple relationships are apparent from the data plotted on ordinary graph paper. In fact, the curves drawn by using some values read from the double log graph give a more reasonable and consistently progressive variation than could otherwise be obtained or justified.

If the frequency curve corresponding to the parabola

$$y = Ae^{-k(\log x - \alpha)^2} \qquad \text{Form } 4b.$$

was representative, we should expect k to be independent of, and $\alpha(=\log x_{max.})$ and $\log A$ to be proportional to, the logarithm of the factor. In such case we should also expect the logarithms of the frequency constants, total number, average grain size, and dispersion (around the mean), to be proportioned to the logged factor. To test this, these constants were plotted against the factor, f, on double log paper and were found to lie on straight lines that we believe to be parallel within the limits of error. This means that these frequency distributions, including their constants, N, x, and σ, vary with the factor according to a law of the type

$$y = cf^a, \qquad (1)$$

where the constant a is independent of the factor. Both parameters, c and a, are probably very complex.

However, this frequency formula does not completely fit any one distribution because of a break that occurs in each curve dividing it into two apparently displaced segments.

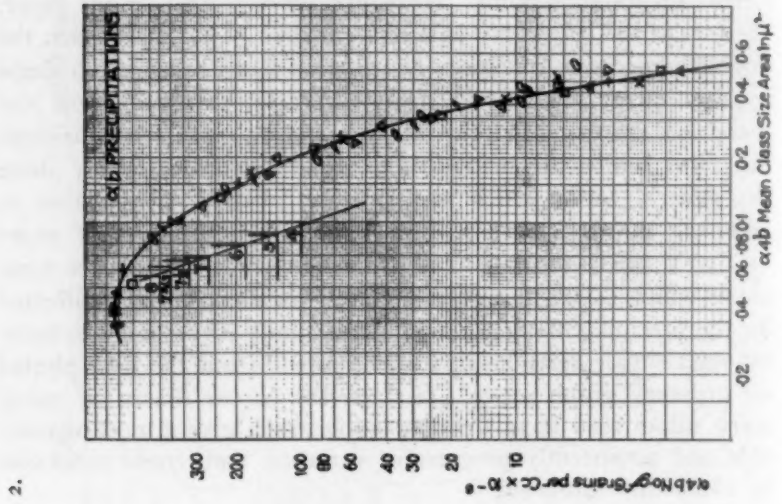
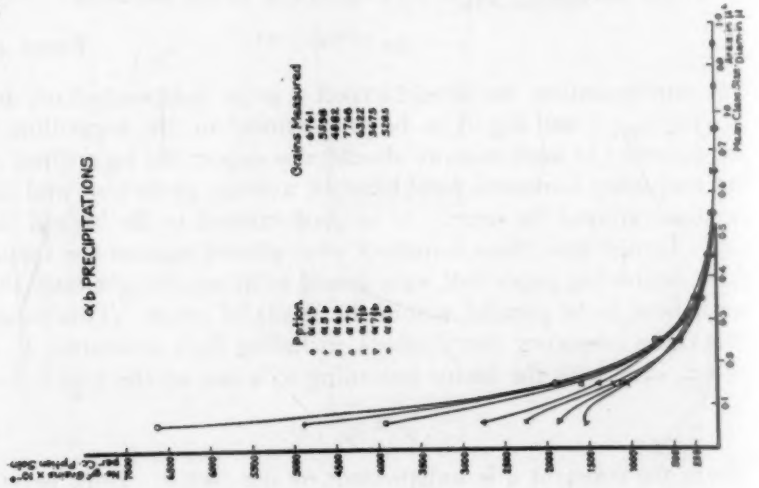

α b PRECIPITATIONS
α4b Mean Class Size Area in μ²
α4b No. of Grains per CC × 10⁻⁶

FIG. 2.


α b PRECIPITATIONS
Grains Measured
Portion

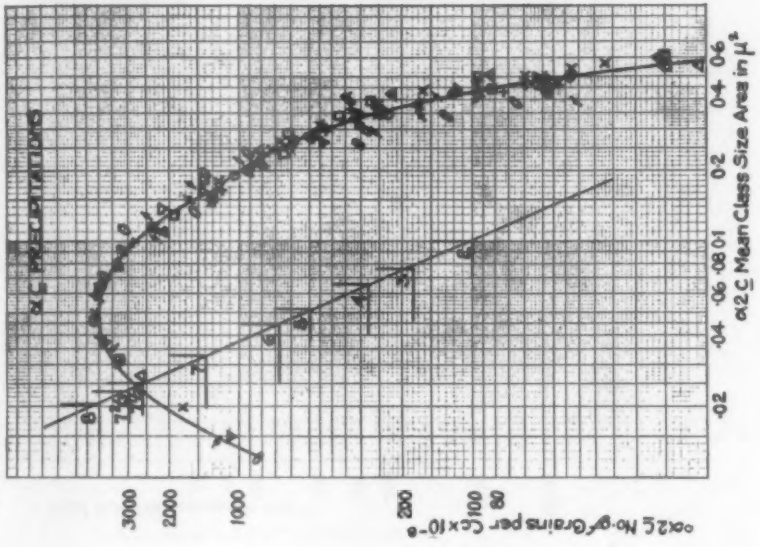
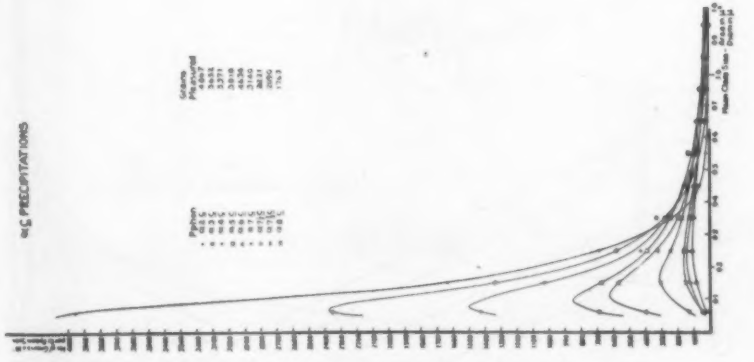

α2 C Mean Class Size Area in μ²
·02 ·04 ·06 ·08 0·1 0·2 0·4 0·6
α2 C No. of Grains per C × 10⁻⁶
3000 2000 1000 200 100 80
α C PRECIPITATIONS

FIG. 3.


α C PRECIPITATIONS

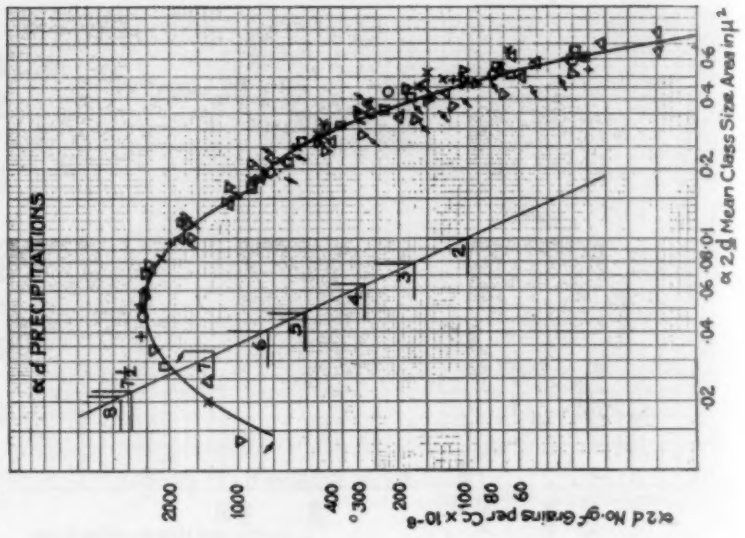

α d PRECIPITATIONS
α 2.d Mean Class Size Area in μ²
α 2d No. of Grains per CC x 10⁻⁸

FIG. 4.

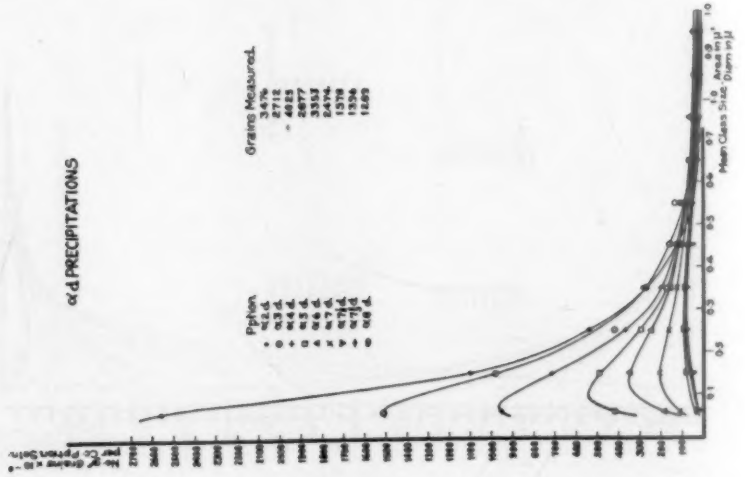
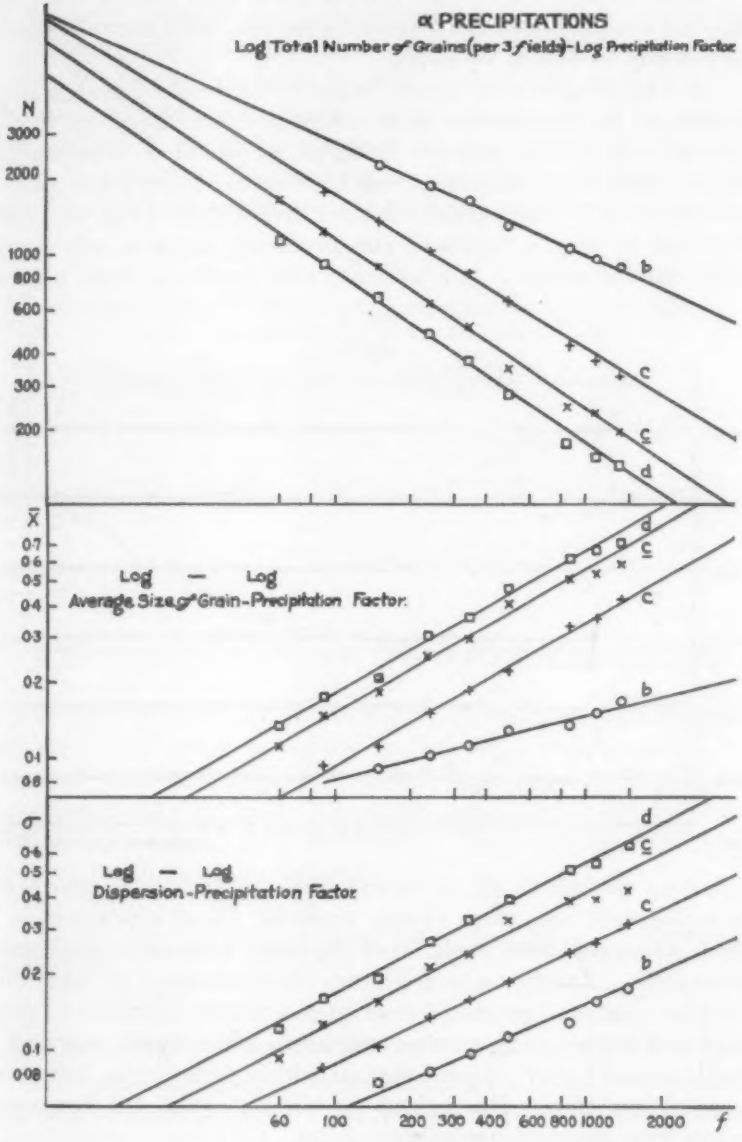

α 4 PRECIPITATIONS
Grains Measured.

FIG. 5.

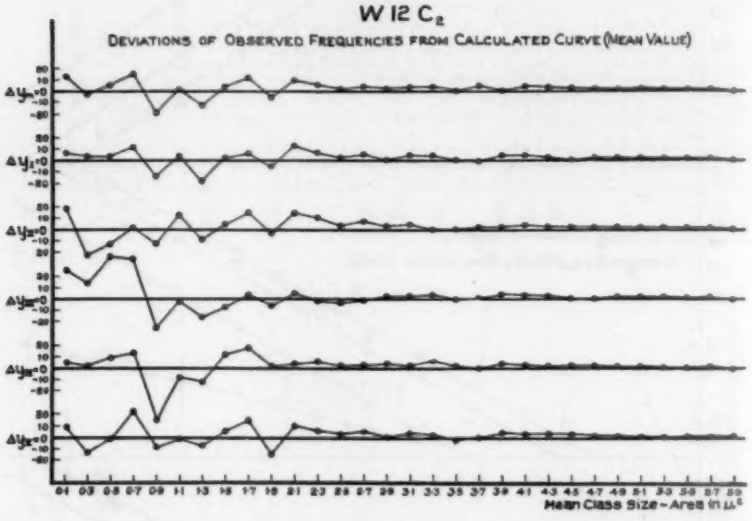

α PRECIPITATIONS
Log Total Number of Grains (per 3 f fields) - Log Precipitation Factor
N
3000
2000
1000
800
600
400
300
200
b
c
ç
d
$\bar{x}$
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0·08
Log — Log
Average Size of Grain - Precipitation Factor
d
ç
c
b
σ
0·6
0·5
0·4
0·3
0·2
0·1
0·08
Log — Log
Dispersion - Precipitation Factor
d
ç
c
b
60
100
200
300
400
600
800
1000
2000
f

FLUCTUATIONS AND DISCONTINUITIES IN FREQUENCY CURVES.

Most emulsion frequency curves show such breaks, although they are not so noticeable on steep curves until they are accentuated by plotting on double log paper.

A considerable time ago it began to be realized that a large portion of the fluctuations on an accurately determined curve was considerably greater than the probable statistical or experimental error. This was definitely proved with the aid of an experimental emulsion. The fluctuations in these five curves (Fig. 6), each obtained by over a thousand measurements, are not only essentially similar when it is considered that errors in total number

FIG. 6.

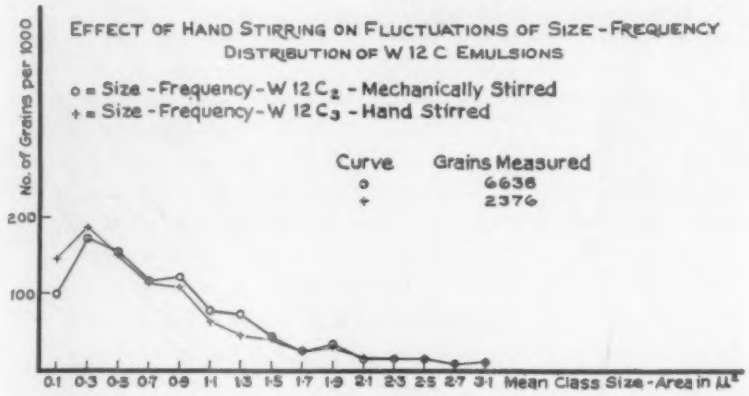


(shifting the whole up or down) and the statistical errors are superimposed, but, they closely resemble those appearing in a curve of an emulsion made from the same formula several years previously. Another size-frequency determination of these five samples combined produced fluctuations almost identical in position and degree. Two other emulsions were made, varying a fundamental factor of precipitation within wide limits, but these same characteristic fluctuations of the observed size-frequency points were apparent in all three.

It was then thought that the regularity of mechanical stirring might set up each time a definite current pattern which would

cause local variation of particle size. Therefore, another batch of the same photographic emulsion was prepared in which the only factor varied was that the stirring was done haphazardly by hand. While the data seem to have been slightly smoothed out, the similarity between the fluctuations of the two curves is remarkable. There is, therefore, a type of fluctuation in size-frequency which is a unique characteristic of the specific precipitate and associated with the conditions of precipitation. This is confirmed

FIG. 7.


EFFECT OF HAND STIRRING ON FLUCTUATIONS OF SIZE-FREQUENCY DISTRIBUTION OF W 12 C EMULSIONS
o = Size-Frequency-W 12 C2 - Mechanically Stirred
+ = Size-Frequency-W 12 C3 - Hand Stirred
Curve Grains Measured
o 6636
+ 2376
No. of Grains per 1000
200
100
0·1 0·3 0·5 0·7 0·9 1·1 1·3 1·5 1·7 1·9 2·1 2·3 2·5 2·7 3·1 Mean Class Size-Area in μ²

by the fact that when the double logged curves of the precipitates, varying in the factor previously studied, were superimposed, the "breaks" also superimposed. It has been suggested[3] that the phenomenon may be due to a rhythmic precipitation having some relation to Liesegang ring formation. There probably are three kinds of fluctuations in frequency:

(*a*) Statistical variations.

(*b*) Unique fluctuations about the normal locus. "Rhythmic precipitation."

(*c*) "Breaks."

APPLICATION OF NORMAL FUNCTION TO PRECIPITATIONS.

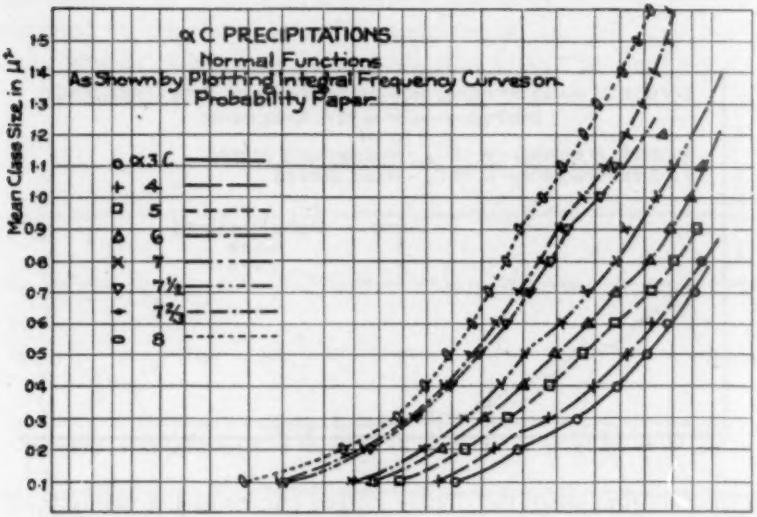
Size-frequency analysis by means of the normal function was described in the first paper. The normal function may be formed graphically by the simple plotting of the summated relative frequencies on probability paper. The advantage and potency of

[3] S. E. SHEPPARD, *Phot. J.*, **49**, 31 (1925).

this method became most evident when applied to the silver bromide precipitates, for in no other way, certainly none so quick and simple, could some of the relationships of this series be observed and expressed.

It is evident from Figs. 8 and 9, as previously suspected from the study of emulsions, that the distributions are composed

FIG. 8.



of separate segments. Moreover, since each segment of the normal functions is obviously a straight line on semi-log paper, the following equivalent formulas [4] apply to each segment.

$$y = N.\frac{\lambda}{\sqrt{\pi}\,x}e^{-\lambda^2(\ln x - \ln x_m)^2} \qquad \text{Form 3.}$$

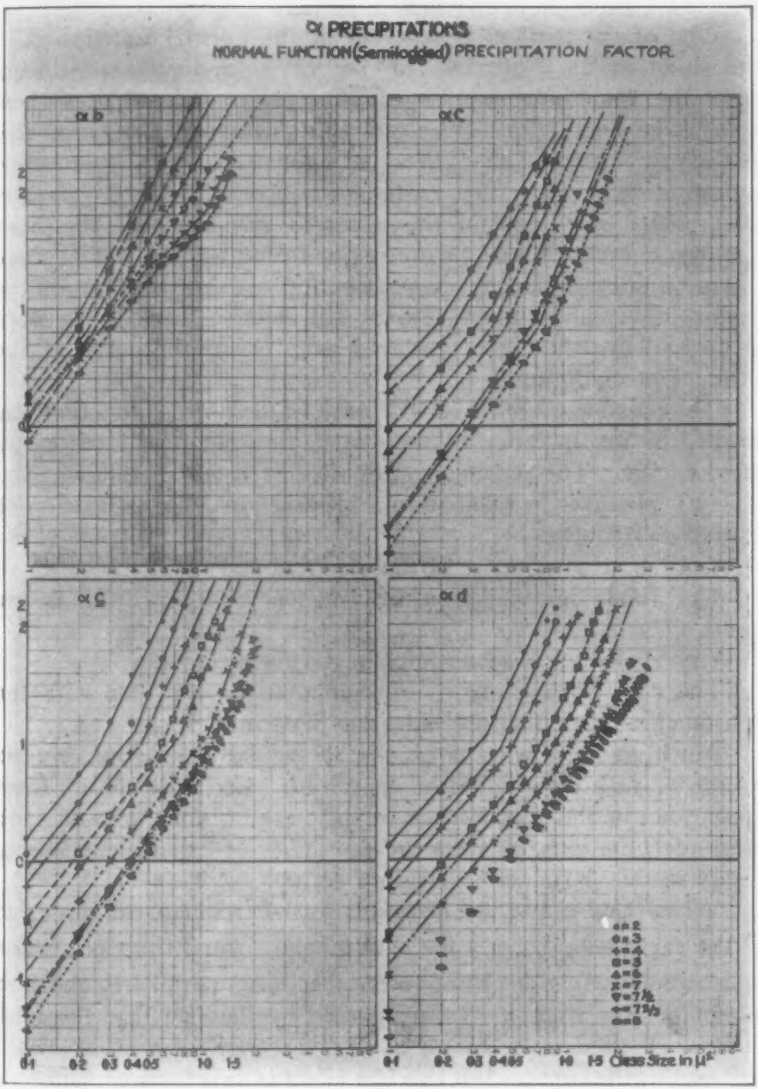
$$y = Ae^{-k(\log x - \alpha)^2}. \qquad \text{Form 4}b.$$

Thus, hypothetically, the distribution extends to molecular size, although the frequencies of submicroscopic particles may be inappreciable because of the marked induction period which this formula may show.

Obviously, these normal functions are merely shifted parallel to themselves by the factor studied. This means that the param-

[4] See first paper.

FIG. 9.


α PRECIPITATIONS
NORMAL FUNCTION (Semilogged) PRECIPITATION FACTOR.
α b
α C
α c
α d
Class Size in μ
n=2
n=3
n=4
n=5
n=6
n=7
n=7½
n=7⅔
n=8

eter, λ, is unaffected, which concurs with our previous observation that $k(\lambda^2)$, determining the shape of the parabolas, on double log paper, is unaffected.

One of the marked advantages of the normal function is in the study of the "breaks" in the curve previously mentioned, since the smoothing process of summation differentiates them from other fluctuations. We can see that the comparative microscopic prominence of the "break" is a matter of the condition of precipitation. If at either extreme the break would be unnoticeable, which may explain the apparent simplicity of the Seed Lantern curves. These 33 precipitates definitely show that these discontinuities in frequency distribution are independent of the factor previously studied (except for relative microscopic position) and are therefore produced as a unique property of the primary precipitation.

The possible cause of such a break in the normal function was studied by manipulation of the distribution obtained from calculated curves. The possible causes may be listed as follows:

(1) Mistakes in calculation. Mistakes in N or formation of excessive frequency.

(2) Systematic error in the experimental method.

(3) Extra accumulation of frequency at, or around, one point.

(4) A definite discontinuity in the frequency law.

The careful checking of all computations together with the constancy of the effect precludes the first cause.

Much thought was given to the second possibility, but no source of such error could be conceived. Certainly the uniform appearance of the phenomenon in various emulsions, as well as in these precipitations, obviates the possibility of experimental peculiarity in this particular laboratory set up.

When there is an extra accumulation of frequency at one value of the variate (y_{s+a}, x_s) the semi-logged normal function, which is accumulative, is displaced to another locus parallel to the first except for the slight curvature caused by the fact that the total number N used as a divisor is not the true integral of either segment of the curve. But this last effect is never one of sufficient degree to account for the "breaks" in the observed curves.

This leaves the fourth suggestion, the possibility of which was confirmed by the formation of just such a broken line on semi-log

paper, from a frequency series composed of two portions computed from formulas with different constants.

Therefore it seems that in a chemical precipitation of silver halide the whole distribution of particles is not governed by a single frequency law.

If a frequency formula were to be applied it is obvious that nothing but the mathematical series previously described [5] would be adequate. However, the great amount of labor involved in fitting each of the 33 precipitations is quite unnecessary for intercomparison, although it is unfortunate that the incompleteness of the distribution caused by optical resolution, together with the class width necessary for practical measurement, makes it impossible to determine the normal function constants with very great accuracy.

[5] See first paper.

The Electric Charge on the Alpha-rays Emitted in a Second by a Gram of Radium. H. JEDRZEJOWSKI. (*Comptes Rendus*, June 20, 1927.)—The number of α-particles ejected from one gram of radium in a second is a quantity that appears in several calculations of radio-activity, such as those relating to the amount of energy produced in a second and the quantity of helium resulting from atomic disintegration. While numerous experimental measurements of this number have been made, there still exists an uncertainty in its value amounting to several per cent. At the suggestion of Mme. Curie the author has undertaken to find the total electric charge on the α-particles emitted in a second by 1 g. of radium. Since each particle carries a charge of two times the fundamental electrical quantity, 4.774 electrostatic units, the number of α-particles is obtained by dividing the total emitted charge by the charge on each particle.

The α-particles emitted by a radium source of clearly determined position pass through a diaphragm and fall on an electrode joined to an electrometer from which the total charge received can be found. To avoid the disturbance of ionization currents a high vacuum was maintained so that there would be almost no gas to be ionized. Both β- and δ-rays were deviated from the electrode by a magnetic field. A device was applied for shutting off the α-rays by a thin layer of aluminum, so that the residual effect of whatever β-rays reached the electrode and of the photo-electric effect on the electrode due to γ-rays might be determined and eliminated. Provision was made to extinguish any effect of radio-active recoil.

The average of thirteen experiments gave as the electric charge emitted by 1 g. of radium in 1 sec. 33.4 electrostatic units. From this is derived the number of particles ejected by the same source in 1 sec., 3.50×10^{10}. This is in good agreement with what Geiger and Werner found by methods of direct counting, but is less than the result of Hess and Lawson, 3.72×10^{10}. G. F. S.

Vitamin C in Pears.—VERRAL C. CRAVEN and MARTHA M. KRAMER, of the Kansas Agricultural Experiment Station (*Jour. Agric. Research*, 1927, **34**, 385–392), have studied the occurrence of the anti-scorbutic vitamin, water-soluble C, in pears, using guinea-pigs as experimental animals. The animals were protected from scurvy by a daily dose of between 10 and 15 grams of raw pear. The raw pear had approximately 25 per cent. of the anti-scorbutic potency of orange juice. The anti-scorbutic vitamin of pears was completely destroyed by the open-kettle method of home canning, and was partially destroyed by the cold-pack method of home canning; it was not influenced by storage of the raw fruit at a temperature of 40° F. J. S. H.

A MICROMETER MICROSCOPE EQUIPPED WITH AN ILLUMINATED SCALE.

BY

D. L. PARKHURST.

Chief, Instrument Division, U. S. Coast and Geodetic Survey.

AN INTERESTING development in filar micrometer microscopes has been made by the U. S. Coast and Geodetic Survey in providing these instruments with an illumination device for reading at night or under poor lighting conditions. The Survey uses such microscopes for reading to one second of arc the circles of its first order theodolites, the angle measuring instruments used in triangulation surveying.

In the past the graduated microscope drums were either made of white celluloid or of silvered metal. As celluloid has a tendency to warp, errors may have been introduced into the readings due to this cause.

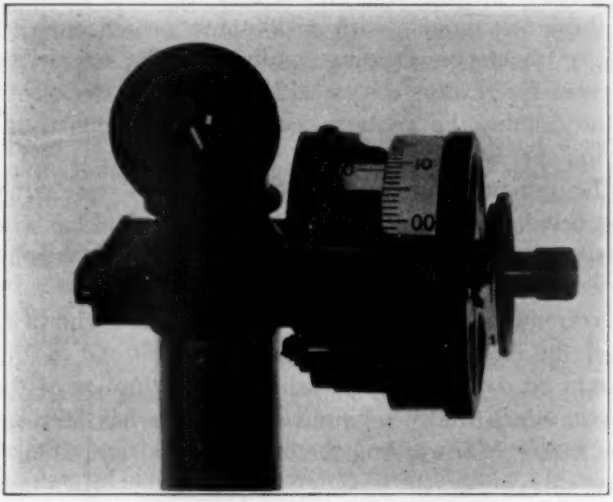
As triangulation observations are made at night in order to minimize the effects of atmospheric refraction and as they must be made in nearly total darkness due to the faintness of the signal light upon which the theodolite is pointed, it has been necessary to use a flashlight in reading the micrometer drum. This necessitated the carrying of the flashlight in the pocket when manipulating the instrument, then, when a reading was made, reaching for it and turning it upon the drum. This light is, of course, very much more brilliant than that of the signal light even as seen through the telescope and has a very objectionable blinding effect upon the observer. Where silvered metal drums are used the graduations have an annoying tendency to disappear in the rays of the flashlight.

In attempting to perfect a more suitable device it was decided to make the graduated part of the microscope drum in the form of a glass ring frosted on the interior and having a small electric bulb inside of it, the light from which causes the graduations to stand out very distinctly and yet, because of the frosting, creates no objectionable glare. The intensity of the light from this bulb may be readily controlled by means of a rheostat so

that when properly adjusted there is little tendency for the iris of the observer's eye to change and cause blinding.

The device as shown in the illustration consists of a ring made of heavy glass tubing about 1¾ inches outside diameter which has been carefully annealed and ground truly circular. This is cemented into a thin brass shell which fastens by friction to the screw of the micrometer, the shell being relieved at the face as much as possible to reduce the weight. The index line is ruled on a segment of the same glass tubing which is held in a suitable metal support on the frame of the box. The under side of both ring and index plate are lightly frosted. On the under side of the box is fastened an insulated metal socket which holds an ordinary flashlight bulb and has suitable terminals for the attachment of the electric wiring. A thin metal shield extends upward from the socket so that the greater part of the front of the drum is shielded from the light, and only the part which is read is illuminated.

FIG. 1.



The graduations were put on by coating the exterior of the ring with an asphalt varnish, then placing the ring in a suitable holder on a dividing head and cutting the lines and figures with a stylus placed in a commercial type of engraving machine. The

inside of the ring was left uncoated during this operation so that the accuracy of the ruling could be readily determined by illuminating the inside. When completed, the interior and edges were coated with asphaltum and the etching performed with hydrofluoric acid.

It is interesting to note that the entire weight of all the parts attached to the micrometer screw is only 3½ grams more than that of the similar parts of metal on another microscope of the same type.

The light inside the ring is controlled by a small key placed in a convenient position upon the body of the theodolite so that the observer may with the same hand illuminate both circle and micrometer drum. He will first illuminate the circle and make a setting of the wires, then, pressing the key which lights the micrometer, he may, with only a slight sideways motion of the head, read the drum.

The advantages of the new style of instrument are that there will be a saving in time and also less fatigue to the observer's eye, which will not be subjected to great changes in brilliancy nor in focus. The micrometers should be more accurate than those used previously as there will be no tendency of the glass to warp due to aging or changes in temperature.

The Tide at Tahiti. H. A. MARMER. (*Jour. Washington Acad. Sci.*, 17, No. 7.)—At Tahiti, it is said, high tide comes at the same time every day. Now there is definite knowledge of this matter, for Mr. H. W. Smith, acting for the U. S. Hydrographic Office, has secured tide records covering a period of several years. The tide gauge with automatic registration was set up in Papeari Harbor on the south coast of Tahiti. The mean range of the tide is .78 ft., the spring range is .97 ft., and the neap range .58 ft. The interval between high waters is 12 h. 09 m., and between low waters 5 h. 53 m. The progression at the time of spring tides is much less than the usual 50 min. and at neap tides is considerably more. "At spring tides high water comes about noon and midnight, and low water about six o'clock both morning and afternoon. At spring tides the tide has its greatest range and is therefore most noticeable while at neap tides the times of high and low water are difficult to determine. Apparently, therefore, the characteristics of the spring tides have been taken as the average characteristics." G. F. S.

New Universal Indicator.—EMIL BOGEN, of the University of Cincinnati (*Jour. Am. Med. Asso.*, 1927, **89**, 199), has devised the following universal indicator for use in the colorimetric determination of hydrogen-ion concentration: Phenolphthalein 0.100 gram, methyl red 0.200 gram, dimethylaminoazobenzene 0.300 gram, bromthymol blue 0.400 gram, thymol blue 0.500 gram, absolute alcohol 500 c.c. The indicators are dissolved in the alcohol; and tenth-normal sodium hydroxide is added to the resulting solution until it becomes yellow in color. In order to determine the hydrogen-ion concentration of a solution, one drop of the universal indicator is added to one cubic centimetre of the solution; a red indicates pH 2.0, orange pH 4.0, yellow pH 6.0, green pH 8.0, blue pH 10.0. These values are approximate; more exact values may be obtained by comparison with buffer solution of known pH to which the universal indicator has been added. Differences as low as 0.2 of a pH unit may be distinguished. J. S. H.

Cultured Buttermilk.—Milk, which has been inoculated with lactic acid bacteria, such as *Bacillus acidophilus*, *Bacillus bulgaricus*, etc., is used on a large scale as a food and as a therapeutic agent. For this reason, the following definition and standard for cultured buttermilk, adopted by the Secretary of Agriculture for the enforcement of the Federal Food and Drugs Act (Food Inspection Decision 210, 1927), is of general interest: "Cultured buttermilk is the product obtained by souring pasteurized skimmed, or partially skimmed, milk by means of a suitable culture of lactic bacteria. It contains not less than eight and five-tenths per cent. (8.5 per cent.) of milk solids not fat." J. S. H.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

FIRE RESISTANCE OF BRICK WALLS.

A PRELIMINARY report giving results of fire tests of brick walls, tested either restrained within rigid frames, or unrestrained with full freedom for expansion and deflection at the top and sides, was published in *The American Architect* September 23 and October 10, 1923. While these tests gave important information on stability and temperature transmission as exposed to the standard test fire on one side for six hours, the ultimate resistance of walls thicker than 8 or 9 inches was not developed in this period; also, there remained the question of ability to support the loads for which walls are designed, throughout the long fires required to develop the limiting permissible temperature rise on the unexposed side. Two panel frames for the large furnace, accommodating walls 16 feet wide and 10 to 11 feet high, were therefore modified to permit application of loads up to 400,000 pounds during the fire exposure. Using these frames, typical wall constructions were subjected to fire tests under a load of 80 lb./in.^{2} for 4-inch walls and 160 lb./in.^{2} for walls of greater thickness. Further tests to determine the ultimate endurance periods for the thicker walls were made in a smaller furnace, as well as tests of plastered walls and some types of hollow walls not included in the original program. The concluding tests were of typical walls dried to constant weight at temperatures near 75° C. (167° F.), to determine the difference in temperature transmission as compared with that of walls which had been seasoned for the usual period of forty to fifty days before testing. It was appreciated that all free water would not be given off in this time, and during the test, evaporation of this water retarded the temperature rise on the unexposed side of the wall. Therefore, the rate of increase in temperature was less than would be the case for party and fire walls when exposed to fire after some years of service in the interior of heated buildings.

Pending publication of results of the tests, Letter Circular No. 228, giving a summary of testing methods and results with

* Communicated by the Director.

walls built of clay and shale bricks, has been prepared to supply information in response to individual requests.

The accompanying table gives the ultimate fire resistance periods developed by clay or shale brick walls. In the walls designated as "solid" in the second column of the table, the bricks were laid flatwise in common or running bond, with one header course for every five stretcher courses. In the hollow "rolok" walls the bricks were set on edge with alternate headers and stretchers, or with two rows of stretchers on edge alternating with one row of headers laid flatwise. In the "rolok-bak" design, the bricks on one face of the wall were laid flat and for the rest of the wall on edge, one header course alternating with six stretcher courses in the face and four in the backing.

Efforts were made to secure ordinary commercial workmanship for both solid and hollow walls. The results in the table are based on the use of Portland cement or Portland cement-lime mortar 1 : 3 by volume, except for solid walls of resistance periods of six hours or less for which 1 : 3 lime mortar can also be used.

Combustible members framed into the wall from the unexposed side generally reduce the fire resistance of the wall, since the time required to ignite their ends, assumed to project 4 inches into the wall, is generally less than that required for the limiting temperature rise on the unexposed side. The resistance of hollow walls can be increased by filling above, below, and between such members with brick and mortar to a depth of not less than 4 inches.

The fire resistance periods in the last column of the table, insofar as they concern walls without combustible members projecting into them, are determined either by the length of time required to attain an average temperature rise of 139° C. (250° F.) on the unexposed side, the temperatures being measured according to present standards under asbestos pads 4/10 inch thick placed in contact with the wall surface, or by failure under working load. For walls of clay and shale bricks the latter occurred only after ten hours of fire exposure with 12-inch walls built of bricks having low fusion point. All other walls carried the load for periods exceeding those determined by the temperature transmission, hence the fire resistance period was governed by the latter.

It will be seen from the table that a considerable increase in

fire resistance is obtained by plaster. The plasters used in the tests, on which the periods for plastered walls are based, were of neat gypsum or Portland cement mixed with three-volume parts of sand. For the Portland cement plasters, lime may be substituted for the cement in volumes up to 50 per cent. of the cement.

The fire resistance periods given are to be taken as the ultimate values for walls of the given type, construction details, and thickness. They are in this sense comparable with crushing strength values obtained in compression tests. In applying constructions that have developed given fire resistance periods to building conditions, a factor of safety should be taken on the results of the tests, to allow for variations in material and workmanship and other conditions that the tests did not fully account for. The use of factors from 1¼ to 1½ is advocated. In the case of the constructions tested, the higher value does not appear to give a greater margin than necessary. On this basis a building condition that can produce a possible fire equivalent to the first two hours of the standard fire test would require a three-hour wall, and a six-hour fire condition, a nine-hour wall.

REACTION OF WATER ON THE CALCIUM ALUMINATES.

INVESTIGATIONS[1] have shown that lime can combine with alumina only in the following molecular proportions: $3CaO.5Al_2O_3$, $CaO.Al_2O_3$, $5CaO.3Al_2O_3$, $3CaO.Al_2O_3$. Tricalcium aluminate appears to be the only aluminate present in Portland cement of normal composition and normal properties. The monocalcium aluminate and the 3 : 5 calcium aluminate occur in cements characterized by a high alumina content. The cementing qualities of the calcium aluminates have been reported in *Bureau of Standards Technologic Paper No. 197*, and the hydration of Portland cement in *Bureau of Standards Technologic Paper No. 43*.

An investigation has been undertaken at the bureau to obtain more information on the mechanism of the reaction of water on the calcium aluminates. Some preliminary experiments had indicated that the cementing qualities of the calcium aluminates and

[1] Rankin, "The Ternary System Lime-alumina Silica," *Am. J. Sci.*, 39, Jan., 1915.

high alumina cements might be closely related to their reaction with water in the formation of metastable or supersaturated solutions of calcium aluminates. It was decided, therefore, to study not only the chemical composition and pH of these solutions as they were formed in the early periods of the setting processes, but also to follow the changes which they underwent in passing from a metastable condition to one of equilibrium. Since the addition of water to freshly prepared tricalcium aluminate, $3CaO.Al_2O_3$, produces a very vigorous reaction, the changes in composition of the resulting solutions could not be followed in the case of this aluminate. Previous investigations have indicated that its setting is due to the formation of hydrated tricalcium aluminate.

The procedure adopted for the other calcium aluminates and a high alumina cement was to shake 50 grams of the anhydrous material for each litre of water for a given time and to filter the mixture rapidly. Samples of this filtrate were taken at once for a chemical analysis and a pH determination. The solutions obtained in the early periods of the setting processes showed an increase in the total lime and alumina with increased time of shaking until a maximum was reached. Further shaking resulted in a rapid decrease which in turn became less as time went on. An apparent state of equilibrium was reached only after several weeks had elapsed. It was surprising to find that these anhydrous calcium aluminates differing so widely in chemical composition reacted with water in the early periods of the setting processes to form calcium aluminate solutions with the molar ratio of CaO/Al_2O_3 in each case very close to 1.1. The pH of these solutions was close to 11.2. At the later periods the molar ratio of CaO/Al_2O_3 in solution had increased with an increase in the pH.

Identical changes in the metastable solutions took place when filtered from the reaction mixture. Part of the lime and alumina precipitated from these clear solutions leaving an equilibrium solution similar to that obtained when the aluminates had been left in contact with the water for long periods. The molar ratio of lime to alumina in solution increased. This was accompanied by an increase in pH to about 11.75. Chemical analysis and petrographic examination of the material precipitated from the metastable solutions indicated that hydrated alumina and hydrated

tricalcium aluminate were precipitated as equilibrium was approached. Calculations based upon electrometric measurements indicate that the aluminate in solution is the calcium salt of monobasic aluminic acid.

It would appear that the cementing properties of the monocalcium aluminate, the 3 : 5 calcium aluminate, the 5 : 3 calcium aluminate and the high alumina cement studied were in part due to the precipitation of hydrated alumina and crystalline hydrated tricalcium aluminate and a metastable and supersaturated monocalcium aluminate solution.

EXPANSION OF CALCINED GYPSUM DURING SETTING.

The expansion which occurs when calcined gypsum sets is one of its important properties. This property makes gypsum an excellent material for casting purposes as it enables the material to give true reproductions of the mould. In some other uses this expansion is undesirable and is to be avoided if possible.

An investigation has been conducted at the bureau to determine whether it is possible by simple methods to control this expansion. It was found that the expansion might be controlled within certain limits by control of the ingredients of plasters and of the conditions under which they are used.

An increase in the proportion of mixing water decreased the expansion. Using a given proportion of water, finely ground gypsum expanded much more than coarsely ground gypsum. With sand as an aggregate, an increase in the proportion of sand decreased the expansion, while a mix made with coarse sand expanded less than one with fine sand when the amounts of sand used were the same.

Retardation of the setting time had little effect on the final expansion, but caused an initial contraction so that the final volume was less than that obtained with unretarded materials. Evaporation increased this effect.

Variations in the time and temperature of calcination were tried, but these produced little differences in the expansion on setting. The use of certain admixtures decreased the expansion to a marked extent.

A report has been prepared giving in detail the results

obtained. Announcement of publication will be made in the usual way in a future issue of the *Technical News Bulletin.*

TRANSMISSION OF VITALIZING OR ACTIVATING RAYS THROUGH GLASS.

IT IS well known to the medical profession that ordinary window glass absorbs the short wave-length ultra-violet solar rays which have the property of preventing rickets. In order to anticipate the question that would arise regarding the total amount of these activating rays in sunlight, especially at sea-level, measurements were made at the noon hour during April, May, and June, of the total amount of these activating rays shut out by ordinary window glass and by the newer glasses and glass substitutes now being marketed.

Starting with ordinary window glass as entirely opaque to the so-called "vitalizing or activating rays," the transmission in this spectral region of the average substitute materials, now being marketed, ranges from less than 5 per cent. to 50 per cent. and even reaches 92 per cent. for the best grades, including pure quartz glass. The amount of these vitalizing rays is about 4 per cent. of the total incoming solar rays or about 0.04 to 0.05 gram calory per square centimetre per minute.

As to the actual effect upon health of using materials which transmit a high percentage of these short waves, the bureau cannot make any statement, since such questions are entirely outside the bureau's field.

ANALYSIS OF THE ARC AND SPARK SPECTRA OF SCANDIUM.

THE chief of the bureau's spectroscopy section recently completed an extensive description of the spectral lines which characterize neutral and ionized atoms of scandium. In coöperation with Professor Russell, of Princeton, an analysis of these spectra has been completed, which classifies nearly all of the observed lines—350 of Sc I and 142 of Sc II. The atom of scandium normally has 21 outer electrons, but 18 of these are in closed stable groups which play no part in the chemical valency or the optical spectrum. The Sc I spectrum is thus a typical three-

electron spectrum in which, according to the alternation law, the energy states are double or quadruple, and the Sc II spectrum which is characteristic of scandium atoms with one electron removed, is described by singlet and triplet states or spectral terms. The various terms in each case are ascribed to specific configurations of the electrons as indicated by recent developments in the quantum theory of spectra, and the observed structures of Sc I and Sc II spectra are found to be in complete agreement with the theory. Terms belonging to so-called spectral series have been detected in both spectra; these point to the energy which is required to remove one of the outer electrons. The outermost electron (21st) of scandium can be removed by impact of a free electron which has acquired a certain velocity by falling through a potential difference of 6.7 volts, and the atom can be robbed of another electron (20th) by colliding with a free electron which has acquired energy of motion by falling through a potential difference of 12.8 volts. These facts are of special importance in the interpretation of the spectrum of the sun.

This work is fully described in *Scientific Paper No. 549*, which may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at five cents per copy.

DENTAL RESEARCH PROGRESS REPORT.

THE annual progress report on the program of dental research being conducted at the bureau in coöperation with the Weinstein Laboratories is being prepared. It is expected that this report will be ready for publication in October. Further announcement regarding the exact date of publication will be given later.

This report will give data on the alloys used in casting dental restorations and will supply details for the preparation of samples sufficiently reliable for use in a research on these materials. It is expected that this report will enable the profession to arrive at a better understanding of what is essential for satisfactory materials to be used in the various types of cast restorations now being supplied in their practice.

Previous reports have stimulated interest in the importance of the physical properties of dental materials and already the

bureau has noticed a tendency for the various organizations interested in dental materials to devote a more intensive study to this type of research. Letters expressing approval of the work and making inquiry regarding details of tests prove the genuine interest in such work. The bureau feels sure that within the next two years the dental college laboratories will be able, as a result of this work, to rate or verify materials and to publish their findings in a more conclusive manner than has been possible in the past, all of which will mean more efficient dental service to the public.

CAROÁ FIBRE AS A PAPER-MAKING MATERIAL.

THE fibre content of many grades of papers—such as book, newsprint, and the cheaper writings—is obtained almost exclusively from wood pulp. But for fine papers in which unusual strength is required—ledgers, bonds, currency—rags are commonly used, and for strong bag or wrapping paper, in which strength is more important than color, worn and salvaged rags, old rope, and waste tow are generally utilized. There is, however, a scarcity of rag and rope stock available for paper-making and the problem of finding new fibres possessing the essential characteristics of these materials is receiving attention. Recent experimental tests at the bureau have shown the fibre of the caroá plant to be a very satisfactory paper-making material and suitable for use with or as a substitute for rag and rope stock in paper production.

Caroá is a plant of the pineapple family and is indigenous to eastern Brazil. The leaf of the plant is about 4 feet long and from 1½ to 2 inches wide, being slightly larger than that of the pineapple, which in certain parts of the world, particularly the Philippine Islands, is extensively used for the manufacture of textiles. By beating the leaf between stones the natives separate the fibre, which, after subsequent retting and washing, is used locally for coarse hand-made twines, nets and rope. Caroá is not recommended for the commercial manufacture of cordage, however, because the fibres, although strong and resistant, are too hard and do not clean easily. The pulpy residue which remains after cleaning rapidly ferments and decomposes in the presence of moisture.

There is at present no organized caroá industry. Available production and cost estimates are somewhat meagre, but indicate that if there were sufficient demand for the fibre, a supply of considerable quantity could be procured, at a cost which would permit the use of the material for paper-making purposes.

Three samples of caroá, each having received different treatment in the separation of the fibre previous to shipment, were employed in the paper-making tests. The tests, which are described in detail in *Bureau of Standards Technologic Paper No. 340,* were made on both laboratory and semi-commercial basis.

The laboratory equipment employed in the preparation of the pulp and its subsequent conversion into paper consisted of a small cylindrical rotary boiler, ½-pound beater, fibre sheet mould, sheet press, and dryer. The fibre sheet mould and sheet press were designed and constructed at the bureau for making small sheets of fibre in laboratory-scale paper-making research, and have proved very satisfactory in the production of small sheets of uniform quality (weight, formation, etc.).

For commercial interpretation and comparison tests were also made in the experimental paper mill of the bureau. The mill is equipped for making paper on a semi-commercial scale under practical mill conditions. The equipment employed in the caroá investigation consisted of a rag duster, rag cutter, rotary boiler, 50-pound copper-lined wood tub beater with manganese-bronze bars and plate and fitted with a washing cylinder, small Jordan with iron bars, a 4-plate screen, and a 29-inch Fourdrinier paper-making machine. The procedure followed in the mill tests was essentially the same as that generally observed in the commercial production of high-grade papers.

A number of cooks were made by the caustic soda process and one by the lime process. Both writing and unbleached papers were produced in the subsequent paper machine runs. The measurements of the finished paper were on samples conditioned in a constant temperature and constant humidity room (temperature 70° F., relative humidity 65 per cent.). Similar tests on high-grade rag, sulphite, and kraft pulps were included for comparison.

The test data show the caroá fibre to be a very satisfactory paper-making material, on the basis of both quality of pulp produced and yield obtained.

When cooked by the caustic soda process, with the smaller

amounts of caustic, caroá produces paper which is excellent for bag or wrapping purposes and is as strong as that made from kraft pulp; with the larger amounts of caustic, the pulp is stronger than sulphite and compares favorably with rag.

The treatment of the plant in the separation of the fibre for transportation is an important factor in determining the characteristics of the paper made therefrom. For the fibrous material separated by mechanical processes the yield is low (40–45 per cent.) and bleaching the pulp is not practical but the paper made therefrom shows unusual strength. Material obtained by retting gives a good yield of pulp (50–60 per cent.) which bleaches easily and produces a strong paper (bursting strength about a point per pound at standard basic weight—pounds per 500 sheets 25 by 40 inches), although of less strength than that made from the fibre obtained by mechanical separation only.

A microscopic study of the structural composition of caroá shows the fibre to be cylindrical and comparatively long and of small diameter. These properties tend to produce good felting of fibres in paper-making and give compactness and strength to the resulting sheet.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

ADDITION COMPOUNDS OF ALLYLTHIOUREA WITH SILVER HALIDES.[1]

By S. E. Sheppard and H. Hudson.

THE preparation of the one to one molecular compounds of silver halides with allythiourea is described. The solubilities of these compounds have been determined at different temperatures.

ON THE CHEMICAL POTENTIAL NECESSARY FOR THE DESTRUCTION OF THE LATENT IMAGE.[2]

By E. R. Bullock.

IT IS shown that part of a latent light-image which is situated on or in the surface of the silver halide grain is destroyed by the action, under usual experimental photographic conditions, of a solution the oxidation potential of which is somewhat higher than that of a decimolar potassium chromate. This corresponds satisfactorily with the susceptibility to oxidation of pure silver element, and is not in conflict with the view that the latent image consists of a minute amount of highly dispersed silver, oxidation of which connotes destruction of the image.

SOME FACTORS IN THE COPPER NUMBER OF CELLULOSE.[3]

By H. LeB. Gray and C. J. Staud.

THE copper number of degraded cellulose is shown to increase when the solution is not stirred during the determination. This is not due to aerial oxidation of the cellulose as indicated by the

* Communicated by the Director.

[1] Communication No. 303 from the Research Laboratories of the Kodak Company, and published in *J. Amer. Chem. Soc.*, **49**: 1814, 1927; *Phot. J.*, **65**: 331, 1927; *Sci. Ind. Phot.*, **7M**: 42, 1927.

[2] Communication No. 315 from the Research Laboratories of the Kodak Company and published in *Sci. Ind. Phot.*, **7M**: 37, 1927.

[3] Communication No. 296 from the Kodak Research Laboratories and published in *Ind. Eng. Chem.*, **19**: 854, 1927.

fact that copper number determinations made in an atmosphere of nitrogen give the same values as those run in air.

The copper number of sulphite is shown to be higher when used in the form of six millimetre squares than when rasped. The reducing groups in cellulose are shown to be partially destroyed by alkaline tartrate as present in the modified Fehling solution used. The effect is thought to be due to preferential absorption of alkali in the Fehling solution and differential rates of reaction between the alkali and the cupric ion with the reducing groups present in cellulose.

NOTES FROM THE U. S. BUREAU OF MINES.*

DESULPHURIZING ACTION OF MANGANESE IN IRON.

By C. H. Herty, Jr., and J. M. Gaines, Jr.

It is generally recognized that the presence of manganese in pig iron tends to prevent high-sulphur concentrations.[1] Further, this beneficial influence is commonly credited to the formation of MnS, which, being sparingly soluble, tends to separate from the liquid iron.

This action of manganese is of considerable importance, therefore, to the maker of pig iron, whether for foundry uses or for steel-making. Of recent years, the tendency of furnace operators has been to charge a higher percentage of manganese, and it seems probable that this course has been adopted partly in recognition of the desulphurizing action of this constituent. Both in the transfer ladle and in the mixer, a lowering of the sulphur content has been noted.

Wheaton [2] followed a month's campaign on a furnace produring high-manganese, high-sulphur iron. The iron was sampled at cast and again just before the transfer ladles were emptied into the mixer. His results were:

Manganese Range.	Per cent. S at Furnace.	Per cent. S at Mixer.
1.00 – 1.50 per cent. (av. 1.39)	0.087	0.041
1.50 – 2.00 per cent. (av. 1.72)	0.070	0.035
2.00 – (av. 2.13)	0.073	0.031

This brings out very clearly the fact that the higher the manganese, the lower will be the residual sulphur.

Wheaton's findings were verified by Herty and Gaines,[3] who followed the same procedure and concluded from their data that the relation of manganese to residual sulphur was one which could be expressed by the equation:

* Communicated by the Director.

[1] Stead, J. E., *Jour. Iron and Steel Inst.*, No. 2, 1892, p. 216; McCance, A., *Jour. Iron and Steel Inst.*, No. 1, 1918, p. 243.

[2] "Yearbook," Amer. Iron and Steel Inst., 1920, p. 393.

[3] Herty, C. H., Jr., and Gaines, J. M., Jr., "Desulphurizing Action of Manganese in Iron," *Trans. Amer. Inst. Min. and Met. Eng.*, October, 1926.

K = (per cent. Mn) × (per cent. residual S) = 0.070. It was added that this relation would be valid only when the iron had previously contained more than the equilibrium concentrations of manganese and sulphur, and when desulphurization by furnace slag was prevented. The temperature for these observations averaged 2400° F. (1315° C.).

In neither of the two researches quoted was a sample of the slag on the ladle obtained. On this account we do not know definitely that the ions in solution were in equilibrium with solid MnS. It is equally plausible that the MnS, after elimination, formed a slag with silica, MnO, FeO, etc., which might be present on the metal surface. If this were the case, a difference in the composition of this slag would account for the variation between the findings of Wheaton and those of Herty and Gaines.

It is evident that there are other factors besides the concentration of manganese which are influencing desulphurization. The problem is really a study of the bivariant system, Fe-Mn-S, the three phases being the vapor, the metal, and as the third either a solid or a liquid MnS slag. Therefore, at a given temperature there will be definite relations existing between the compositions of the three phases. As we are ignorant of conditions in the vapor phase, we are confined to consideration of equilibrium between slag and metal. This reasoning shows us that our other factors will most certainly include the temperature and slag composition, and possibly the effect of other substances in the solutions. The present report deals only with the first-named variable, temperature. No attempt was made to control slag composition, except to carry out all determinations under as nearly identical conditions as possible. The effect of temperature is so striking that it seemed advisable to make several preliminary runs, without regard to the slag, in order to verify the influence of the former.

In carrying out the determinations, an Ajax-Northrup high-frequency induction furnace of about 100 pounds' capacity was used. A charge of boiler punchings and petroleum coke was melted in a graphite crucible, with enough ferro-silicon to give samples that could easily be drilled. Ferro-manganese in the desired amount was next added and the metal surface was covered with coke to prevent oxidation. Temperatures were measured with a disappearing filament pyrometer sighted on the bottom

of a closed silica tube inserted in the iron. No correction for emissivity was employed. When the temperature reached the desired level, a predetermined quantity of iron sulphide was added. Samples were taken with the temperature falling, in order to be sure that saturation of the iron with MnS was attained.

(1) The relation between the temperature and the solubility product, (K = (per cent. Mn) (per cent. S)), for MnS in iron in contact, presumably, with solid MnS, has been determined over the range 1100 – 1440° C. and 1.00 per cent. Mn to 1.75 per cent. Mn. The amount of dissolved MnS increases rapidly with the temperature, the change in the product for this range being from 0.030 to approximately 0.650.

(2) The composition of any liquid slag formed is pointed out as a probable factor in determining the magnitude of K.

(3) Data on the effect of oxidation on desulphurization were obtained.

(4) The desulphurizing action of manganese in the transfer ladle has been shown. However, the higher temperatures prevailing within the blast furnace and in the open hearth make it probable, in view of the results here presented, that manganese cannot act in these cases directly as a desulphurizer; it may, and very probably does, assist indirectly other desulphurizing reactions. Further details are given in Serial 2817.

APPARATUS FOR VACUUM DISTILLATION OF LUBRICATING AND HEAVY PETROLEUM OILS.

By Martin J. Gavin and Arch. L. Foster.

DURING the present study of lubricating oils in the San Francisco laboratory of the Bureau of Mines it became desirable to distill oils used in the experimental work at pressures as low as 10 mm. (mercury column) absolute. In the effort to overcome difficulties and eliminate sources of error special apparatus was finally developed.

By this apparatus and method it is a comparatively simple matter to obtain clean-cut distillations, the data on which are accurate, comparable, and reproducible. Vapor temperatures, especially, are more reliable and reproducible than with any other method so far attempted.

Examples of data obtained, using this apparatus, are shown in Serial 2819.

THE USE OF SOLVENTS FOR DEWAXING PARAFFIN-BASE CRUDE OIL.

By H. M. Smith.

IN STUDYING the chemistry of lubricating-oil fractions from so-called "paraffin-base" crudes, one of the first requisites is a method for the separation and removal of waxy material. A method utilizing solvents for this purpose is described in this report, together with preliminary experiments with solvents that led to its development. The solvents actually used are secondary butyl alcohol, acetone, and mixtures of these. Isopropyl alcohol was also studied.

Test-tube experiments indicated that the isopropyl alcohol ($CH_3 - CHOH - CH_3$) as received did not offer any advantage over acetone, but after dehydrating with solid NaOH and anhydrous $CuSO_4$, it was an excellent solvent.

The secondary butyl alcohol ($CH_3 - CHOH - CH_2 - CH_3$) had a boiling range of 94° to 102° C. and had been dehydrated to about 98 per cent. by volume. This alcohol appeared to dissolve the oil readily and to give good separations of the oil and wax.

Filtration in a small experimental Shriver filter press using paper with cloth backing was not successful, as the pressures developed by the pump forced the small crystals through the filtering medium.

Centrifuging was very successful, but because of limited equipment was very slow for the handling of large amounts; to overcome this difficulty cold settling was tried. Various mixtures of oil and solvents were prepared, placed in Florence flasks and allowed to stand at a temperature of 1 to 2° C. for thirty-six hours. Best results were with the following mixture, so a large-scale test was made.

Fifteen gallons of oil, 20 gallons of secondary butyl alcohol, and 10 gallons of acetone were thoroughly mixed in the tank, and then allowed to settle at 1 to 2° C. (34 – 36° F.). At the end of twenty-four hours, 30 gallons 66 2/3 per cent. of clear supernatant liquid were drawn off, the wax level being approximately as shown by line *W* in Fig. 1. Twenty-five gallons of solvent were then added to the wax, the mixture stirred and again allowed to settle. At the end of twenty-four hours the entire supernatant liquid was drawn off.

The solvent is removed from both the oil and wax by distillation with natural gas. A 5-litre flask in a bath of boiling water is a convenient still. A stream of natural gas is passed through the solution in the flask, and removes the solvent very rapidly. The recovered solvent may be used successfully for the wash mixture, especially when corrected for distillation loss by the addition of a small amount of acetone.

Altogether 140 kg. of gasoline-free oil were treated in this manner, and the recoveries were as follows: Oil, 72.8 per cent.; wax, 25.7 per cent.; loss, 1.5 per cent. The wax separated in this manner from this particular crude oil is very similar to yellow vaseline. The pour-point test of the dewaxed oil is 15° F., as against 25° F. for the gasoline-free crude.

The above experiments indicate that secondary butyl alcohol has possibilities as a solvent for the removal of wax from paraffin-base crudes. Its solvent properties may be utilized to their fullest extent, or they may be modified by the admixture of another solvent such as acetone. The manner in which it is used depends upon the method of dewaxing. Further details will be found in Serial 2822, just issued.

Microbes Produce Copper. (Department of the Interior, Press Memorandum.)—Copper is ordinarily thought of as one of our most valuable metals won from the earth through the skill of the miner and made into usable form by the metallurgist; but according to a recent report of the Department of the Interior, it now appears that metallic copper may be deposited—in relatively small quantities to be sure—through the action of bacteria.

During a survey of the region near Cooke, Mont., by the Geological Survey, spongy masses of native copper were found in the black muck of a bog. Several bodies of pyritic copper ore crop out about half a mile above the bog. This ore weathers rapidly, and the copper is removed from it in solution as cupric sulphate. Redeposition of the copper as native metal only in the black muck and in none of the gravels and sands in the vicinity was ample proof that something in the muck had caused the precipitation of metallic copper from the sulphate solution, but the identity of the precipitating agent remained to be determined. Consideration of inorganic processes was discouraging, but preliminary experiments with the copper-bearing muck led to more carefully controlled experiments which proved beyond question that the copper was precipitated through the agency of certain bacilli. These experiments are described in some detail in Bulletin 795-C, of the Geological Survey —"Organic Precipitation of Metallic Copper," by T. S. Lovering.

Rancidity in Fats and Oils.—L. A. SPIELMAN (*Chemist Analyst*, 1927, No. 49, 7) comments on the Kreis test. In this test, 10 c.c. of a fat or oil are shaken for 30 seconds with 10 c.c. of concentrated hydrochloric acid (specific gravity 1.19) and 10 c.c. of a 0.1 per cent. solution of purest phloroglucinol in purified ether, using a test-tube 10 inches long and one inch in diameter. The aqueous and ethereal layers are permitted to separate. If the oil or fat is rancid, a pink color is imparted to the aqueous layer; the intensity of the color is roughly proportional to the degree of rancidity. Some samples of freshly refined cotton-seed oil may give a trace of pink in this test. As a rule, a fat or oil, which gives a slightly pink color in this test but does not taste or smell rancid, is in a state of incipient rancidity. J. S. H.

Pharmacy and Chemistry.—The graduation address at the 105th annual commencement of the Philadelphia College of Pharmacy and Science, June, 1927, was delivered by EDGAR FAHS SMITH. In this address (*Am. Jour. Pharm.*, 1927, **99**, 385–389), Doctor Smith calls attention to the influence of two pharmacists, Geoffroy and Scheele, upon chemistry. Stephen Francis Geoffroy, a Frenchman born in 1672, developed in 1718 a theory of chemical affinity based on Newton's doctrine of gravitation. Carl Wilhelm Scheele, a Swede, discovered chlorine and barium and numerous inorganic and organic compounds. J. S. H.

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LIBRARY NOTES.

RECENT ADDITIONS.

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BOOK REVIEWS.

Pharmaceutical and Medical Chemistry. By Samuel P. Sadtler, Virgil Coblentz, and Jeannot Hostmann. Sixth edition, revised and rewritten by Freeman P. Stroup, Ph.M., Professor of General Chemistry, Philadelphia College of Pharmacy and Science. xvi + 748 pages, 8vo. Philadelphia and London, J. B. Lippincott Company, Copyright, 1927. Price, $7.

The first edition of this treatise appeared in 1895, the fifth edition in 1918. The present edition has been revised by Professor Stroup to conform to the current revision of the Pharmacopœia of the United States (U.S.P.X)

and the National Formulary (N.F.V), and the latest edition of New and Non-official Remedies (N.N.R., 1926). The section on chemical physics, which was included in previous editions, has been omitted from this edition. The book is divided into three parts which are devoted, respectively, to chemical theories and the non-metals, the metals, and organic chemistry. The value of the book is increased by such information as the history of elements and compounds, their official names in pharmacy, and their use in volumetric analysis, as well as data on their occurrence, preparation, chemical and physical properties, uses, and detection. Attention is paid to such timely subjects as the rare gases of the atmosphere, radio-activity, atomic structure, isotopes, hydrogen-ion concentration, synthetic drugs, and electrolysis. The tendency is to prefer glucinum to beryllium, and niobium to columbium. The classification of the proteins is quite different from that of the American Physiological Society and the American Society of Biological Chemists. While the book contains much chemical data of medical interest, it does not enter upon the domain of physiological, pathological, and clinical chemistry, *i.e.*, the chemical activities and products of the animal body in health and in disease. An excellent index completes the volume. The treatise is a valuable reference work for the chemist, the pharmacist, the physician, and the person who has an interest in chemistry as a cultural subject.

JOSEPH S. HEPBURN.

EQUILIBRIA IN SATURATED SALT SOLUTIONS. A summary of the results of the study of the heterogeneous equilibria which exist in aqueous solutions of electrolytes, by Walter Charles Blasdale. American Chemical Society Monograph Series. 197 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1927. Price, $4.50.

This book, although treating a technical subject, discusses the topic from a thermodynamic viewpoint. The introductory chapters on the equilibria of water—a one component system—and of the system composed of water and a soluble salt lead gradually to a comprehension of the validity of the phase rule and to a knowledge of the conceptions serving as the basis of equilibria diagrams in general. The following chapters on hydrates and solid solutions contain a lucid description of the properties of these systems which indicate clearly to the reader the various factors which must be regarded in considering the equilibria of any system, any of whose components may belong to the above class. The remainder of the text, after the preliminary but useful analysis of the fundamental properties of salt solutions in general, considers the various general types of heterogeneous equilibria which exist in systems composed of water and one or more electrolytes, together with the various methods employed in their diagrammatic representation, the whole being illustrated by aptly chosen systems for which fairly accurate data are available.

The volume presents the subject in a very intelligible manner and should be of considerable service to students of chemistry and those whose activities lie in other fields, although it does not contain very much material which will interest the specialist in this subject.

ARTHUR BRAMLEY.

ACETATE SILK AND ITS DYES. By Charles E. Mullin, M.Sc., with a foreword by Louis A. Olney, D.Sc. 473 pages, illustrated, 8vo. New York, D. Van Nostrand Company, 1927. Price, $6.

The manufacture of substitutes for natural fibres has grown to an enormous extent, and those which are especially intended to substitute the product of the silk-worm may in time give rise to an international problem. Oil and rubber are ruffling the waters of diplomacy, and it has been hinted that as the manufacture of real silk is a basic industry of Japan, a serious injury to that industry may arouse irritation in that country. "Business is business," however, as Mr. Grewgious said to Rosa Bud, and the artificial fibre industry will go on its own way regardless of other interests. It is known to all who have to deal with this type of manufacture that the term "artificial silk" is incorrect. The products are not of the same composition. To avoid such confusion the term "rayon" has been introduced and is now widely used.

The work in hand deals almost entirely with the problems of the dyeing of one type of product. Natural animal fibres, such as silk and wool, take dyes readily, but cotton and linen are more resistant and in many cases require the use of intermediates, the so-called mordants. The book is limited to the problems of cellulose acetate. The earliest reference to this ester seems to have been by Schützenberger in 1865; the next investigator (Worden) taking the matter up in 1919. Since that time research and practical application have been carried out with great industry, as the long list of patents given in the book shows.

Among the forms of artificial fibre, cellulose acetate holds a definite field of popularity on account of its dyeing possibilities, but this advantage is of recent development. A few years ago its usefulness was very much restricted by reason of lack of knowledge of treatment of it in the dye-house. On this account, this book has a highly useful field and is opportune. It is very comprehensive in its text, giving in great detail the methods of dyeing. A large number of persons, experienced in the several special fields covered, have contributed to it, so that the information is accurate. Most of the contributors are of this country, but assistance has also been received from abroad. The statistics of the production for recent years show the rapid increase of popularity of these substitutes. The production by the principal American companies in 1925 was a little over fifty-two million pounds; the estimated production for 1927 is over eighty millions. The world production for 1926 has been estimated at over two hundred million pounds. The hosiery industry absorbs about one-quarter of the output.

The text traces in an interesting manner the history of the industry, which is the not infrequent story of anticipation by suggestion without any actual experimentation, and then, after a considerable period, a practical investigation. It is not clear to the reviewer why the book has been printed on such highly calendered and heavy paper. It makes a very heavy book and must add considerably to the cost. There are about a dozen photomicrographs, but these could be printed on a few insert pages at the back of the book. They are large square blocks, with no indication of the degree of magnification. They would have been more vivid and suggestive if the

original circular field of the photomicroscope had been engraved and the magnification indicated. The literature of the subject of acetate silk is now very large and is growing at a rapid rate. This work will enable those interested to learn the present state of the important problem of dyeing the product. HENRY LEFFMANN.

ALUMINUM BRONZE POWDER AND ALUMINUM PAINT. By Junius David Edwards, Assistant Director of Research, Aluminum Company of America. 104 pages, illustrations, 8vo, cloth. New York, The Chemical Catalog Company, Inc., 1927. Price, $3.

The economical production of aluminum is an industry of comparatively recent development. At the time of the Civil War in the United States it was merely a special product of certain manufacturing laboratories engaged in furnishing unusual specimens. An ingot weighing an ounce, valued at five dollars, was in the collection of the Central High School of Philadelphia. Persistent work, however, guided by the principles of electrometallurgy, has brought the production of the metal to such a point that it is now one of our most familiar materials. Most striking, perhaps, is the way in which it has entered into household economy. The up-to-date kitchen shines with it. Its alloys have also been of much value. The present work is limited to one type of alloy, namely, the bronze powder. This we are informed was an offshoot of the goldbeater's art, though the bronze powder originally produced was made from brass. Bessemer was among the early developers in the manufacture of this powder. By the end of the nineteenth century aluminum had become commercially available as an ingredient of alloys and as a source of silver powders. This, as is well known, is now one of our most familiar metallic ingredients for paints. Although not made from an alloy of the nature of bronze, it is called aluminum bronze powder. In this respect it confuses somewhat with a very vivid copper aluminum alloy containing 10 per cent. copper introduced many years ago under the name of "aluminum bronze." The present work covers all the data concerning the making of this aluminum bronze powder, the employment of it in paints, the different mixtures, the testing of the material, the durability of the several forms, including its use for inks. It is therefore a highly specialized work, but is very comprehensive and thorough in its data. HENRY LEFFMANN.

A TEXT-BOOK OF INORGANIC CHEMISTRY. Edited by J. Newton Friend, D.Sc., Ph.D., F.I.C. Volume vii, part 1, Oxygen. xxiv–370 pages, 8vo. Volume ix, part 2, Iron and Its Compounds. xxv–265 pages, 8vo. London, Charles Griffin and Company; Philadelphia, J. B. Lippincott Company, 1924, 1921.

These are two volumes of a work now well known to chemists, as it has been in progress of publication for some years. It is a most comprehensive and searching study of the literature and constitutes, therefore, a very satisfactory work of reference along all lines of descriptive chemistry. Some features deserve special commendation, among which is the extensive coördination in the chronology of the journals relating to chemistry which is a great convenience in verifying references.

The two volumes, however, seem to be rather belated. Volume vii, part 1, devoted to oxygen (including the atmosphere, water and hydrogen dioxide) is by the editor and Dr. Douglas F. Twiss. The preface is dated November, 1923, and in the list of elements according to the periodic system it is stated that the atomic weights are from the international table of 1918. In some respects the data in the text are out of date. Thus, on page 166, it is stated that the highest point reached by an airplane is 32,418 feet (September, 1919), but this altitude has been far exceeded.

Similarly, Volume ix, part 2 (devoted to iron and prepared by the editor alone), is dated March, 1921, making the book over six years old. In view of the rapid progress of chemistry such delays of issue seem regrettable.

The awkward system of volumes issued in parts is continued. The series is advertised to consist of ten volumes, but by this peculiar subdivision the subscriber does not know how many individual issues he must purchase. It is also doubtful if the arrangement according to the periodic system is of practical advantage in a reference work. It may be of value in teaching the elements of the science and it has proved of value in directing research, although the system of atomic numbers seems to have been of more service, but the research worker and student in practical chemistry, to whom the series will be of most use, will find an alphabetical arrangement more convenient. The elements considered in each part should be indicated by symbols on the back. In several ways, such as the use of Roman numerals in the preliminary pages, the work shows British conservatism. A commendable feature is that in all references the year and volume are given, whenever the periodical has both these data.

These volumes, as those previously reviewed, show that an immense amount of research has been devoted to the accumulation of data and the result is a comprehensive treatment of each subject. HENRY LEFFMANN.

PHOSPHORIC ACID, PHOSPHATES, AND PHOSPHATIC FERTILIZERS. By Wm. H. Waggaman assisted by Henry W. Easterwood. American Chemical Society Monograph Series No. 34. 370 pages, illustrations, 8vo, cloth. New York, The Chemical Catalog Company, Inc., 1927. Price, $7.50.

Phosphoric acid is interesting both from its importance in the phenomena of life and in the variety of combinations. "Without phosphorus no thought" was the dictum of a German chemist. Under the modern principles of scientific agriculture, it is one of the important fertilizers. It appears, however, as indeed might be expected, that mankind used phosphatic materials long before the exact composition thereof was known. In a historical note the author refers to the use of refuse material of various types, including bones, in fields and gardens. Guano was not introduced into use in Europe until 1840, but it had been used by the aboriginals in Peru long before Europeans visited that region. It is stated that phosphoric acid was first recognized in 1743 by Margraff, but it was much later when Gahn found phosphates to be an essential constituent of bones. In the historical note, the progress of the industry is described interestingly, including the introduction of phosphate powders for baking purposes and also the interesting and extremely important

development of Thomas and Gilchrist by which phosphatic iron ores may be utilized in the production of a high-grade steel. In the introduction, much space is given to the nature of the several oxides and the acids derived from them. Space is also given to the relations of phosphoric acid in the animal economy and its use in agriculture. A general account is then given of the mineral sources of phosphates. Then follows a comprehensive account of the phosphate deposits in various parts of the world, beginning with those of the United States. The different forms of phosphates as marketed are then considered, including phosphate baking powders, phosphates as water softeners and various miscellaneous uses among which are their applications in glass and china manufacture, in dental cements, photography, fireproofing and in fermentation processes. It will be seen therefore that this is a very comprehensive and commendable account of phosphates in all their practical applications.

HENRY LEFFMANN.

PHOTOGRAPHY: ITS PRINCIPLES AND APPLICATIONS. By Alfred Watkins, F.R.P.S., Progress Medallist of the Royal Photographic Society for 1910; Past President Photographic Convention. Third edition, revised. xvi–336 pages, 20 × 15 cm., cloth. New York, D. Van Nostrand Company, Inc., 1927. Price, $4.

If photography as a hobby has fallen a bit out of favor in recent years, it is rather because a certain degree of stabilization of its extensive possibilities and perhaps too because of having to divide the honors of popular favor with the results of other scientific achievements. We find few amateurs who do their own dark-room work and incidentally a certain amount of experimenting. Most of them are content to make the exposure which now is finished by the excellent facilities afforded by the myriad service stations which are in evidence everywhere.

Photographic art may well rest on its oars in the present state of its development for there has accumulated a wealth of material which is continually finding commercial and technical application of a highly refined type. However, these recent developments are in the hands of workers in research laboratories of scientific institutions or manufacturing firms. So photography is to-day undergoing a process of refinement rather than of evolution, at least in the monochromatic field. In the color field there appear some signs of coming evolution that may displace the only partially satisfactory autochrome color process of the Lumières which has consistently maintained its supremacy over a long period of years.

The author whose work has been long and widely known, especially in the field of exposure and development control, is especially qualified to present an authoritative account of the principles of photography and its applications, and if he does not describe all that is up-to-the-minute, he at least gives us a well-arranged though necessarily not exhaustive presentation of the varied elements which enter into practical photography. The all-important topics of exposure, development and printing and their control are in especially good hands and receive the sort of treatment which will make a strong appeal to the practical worker. Measures are given in avoirdupois, apparently a time-honored habit with photographic workers which seems out of keeping with

the practice of research workers the world over, to whom anything but the metric measures would be unthinkable. Modern applications are not overlooked, color photography is dwelt upon at considerable length. Then we have the cinema, survey photography, photomicrography, X-ray photography, process work, and pin-hole photography. The latter chapter includes recent information on the sizes and construction of pin-holes.

The work is one in which both the active worker and amateur will find a valuable fund of information. LUCIEN E. PICOLET.

THE CONQUEST OF THE AIR. By C. L. M. Brown, M.A. 126 pages, 8 plates, 12mo. The Oxford University Press, American Branch, New York, 1927. Price, $1.

This book exemplifies the old adage that "good goods come in small packages." In a compact and convenient pocket volume all the important steps in the development of aviation are presented. The eight plates add to the vividness of the descriptions.

There seems to be no reason to doubt that at a very early period man felt a desire to fly, but it has taken many centuries to obtain such conditions as will really count as a conquest of the air. Even now the frequent fatalities show that the control is far from complete. It is probably true that many of these accidents are due to lack of care or to a desire for spectacular effects, but there is still left a number of instances that cannot be so explained.

A creditable feature of the book is the recognition of Langley's work. In the interest of the Wright Brothers, the labors of Langley have been seriously deprecated. Langley was actuated by the true scientific spirit. He wanted to demonstrate that the flight of a heavier-than-air machine is entirely possible. We know now that it is, but in the period of his earlier experiments he had doubters and discouragers all around him. Even such eminent and well-informed men as Lord Kelvin and Simon Newcomb strongly expressed skepticism as to Langley's expectations. One sentence in the book deserves to be borne in mind by all who wish to give credit to pure scientific research: "The Wright Brothers owed nothing to Ader or Maxim; their debt to Langley cannot be denied." Mention is, of course, made of Leonardo da Vinci, who discussed the question of flight to a considerable extent, but it has seemed to the reviewer that he rather "thought of" than "thought out" a method.

HENRY LEFFMANN.

TRAITÉ DE BALISTIQUE EXTÉRIEURE. Par L'Ingénieur-générale P. Charbonnier, Inspecteur-générale de l'Artillerie Navale. Tome I, Balistique Extérieure Rationnelle, Les théorèms généraux de la balistique, ix–637 pages, 25 × 16 cm., paper. Price, 75 francs. Tome II, Balistique Extérieure Rationnelle, Les théories balistiques, 797 pages, 25 × 16 cm., paper. Price, 150 francs. Paris, Gaston Doin and Gauthier-Villars, 1921 and 1927.

With very few exceptions every activity in military operations has a counterpart in civil life. The ballistic art may be properly classed among these exceptions unless we consider the industry of sportsman's fire-arms, arms for personal defense and the like as such a counterpart. Ballistic problems arising in the use of this type of arms are scarcely comparable to those of modern

artillery with its long ranges, indirect method of aiming, and multiplicity of problems of barrage and machine-gun danger-zone control and again the very special recent problem of fire at enormous ranges at which the projectile must pass through atmospheric strata of varying density. Consequently a ballistician capable of coping with the problems of modern artillery will scarcely be found "ready-made" in any peace-time industry and must be especially trained for that exclusive calling so necessary to the national defense. Only within the restricted circles of various military commissions is the subject studied at length and the author makes a plea in view of its importance and its recent progress resulting from an awakened interest on the part of numerous technologists who were drafted into artillery service during the World War for its foundation as a special division of scientific teaching comparable to that of astronomy, of which it is the terrestrial branch.

The author's object in preparing the present treatise has been to collect all available information on the subject classified in logical sequence and analyzed in detail. The work is divided into six volumes, each of which covers a general division of the subject. Vol. I, The general theorems of ballistics. Vol. II, Ballistic theory. Vol. III, Secondary ballistic problems. Vol. IV, Experimental exterior ballistics. Vol. V, History of exterior ballistics. Vol. VI, Numerical tables.

Of these, Vols. I and II are now issued. Vol. I which treats of the fundamental principles is in four main divisions. In Book I we have numerous and varied aspects of the familiar problem of the trajectory of a projectile in a vacuum. In Book II the equations of motion in air are considered. Book III treats of the theorems which may be established by a discussion only of the differential equations of the motion. Book IV makes an analytic statement of the ballistic problem, and points out the difficulties of a rigorous solution and defines the results attained.

The second volume is an elaboration of the first. In Book V we have a consideration of the case where the air resistance $F(v)$ is a monomial expression. Book VI is devoted to an analysis of flat trajectories. Special equations of motions for the study of particular regions of the trajectory are developed in Book VI. In Book VII the determination of trajectories is described at length.

The analytical methods are of a type familiar to readers of undergraduate university training and any one so qualified who seeks a sound knowledge of this application of analytical mechanics will not err in making use of this comprehensive work.

LUCIEN E. PICOLET.

PHYSICS FOR COLLEGES. By H. Horton Sheldon, Ph.D., C. V. Kent, Ph.D., Carl W. Miller, Ph.D., and Robert F. Paton, Ph.D. vi–655 pages, illustrations, 8vo, cloth. New York, D. Van Nostrand Company, 1926. Price, $3.75.

The highly descriptive appearance of this useful book should not mislead us into the belief that it is superficial or that its field is limited to colleges. It is an excellent reference book and its place is in the library of any engineer not practising physics as a specialty and occasionally anxious to "check matters up."

NICHOLAS W. AKIMOFF.

THE MATHEMATICS OF ENGINEERING. By Ralph E. Root, Ph.D., Professor of Mathematics and Mechanics, Post-graduate School, United States Naval Academy. xiii–540 pages, illustrations, 23 × 15 cm., cloth. Baltimore, The Williams and Wilkins Company, 1927. Price, $7.50.

There is no limit to the diversity and thoroughness of the mathematical attainment that may be required by an active practitioner in any branch of engineering, but there is a practical limit, the time-limit, that must govern both plan and exhaustiveness of treatment of the mathematical groundwork for a class of technical students whose individual talents may vary widely despite a high average standard of ability. Accordingly the mathematical teacher who undertakes the important duty of supplying this very essential basis of sound engineering is confronted with the task of inventing methods of presenting the deduction of a wide diversity of theorems with consistent brevity in an unmistakably convincing fashion.

Like several other authors of modern texts on the theory of functions, Doctor Root departs from the traditional custom of the old-style text-books of treating as distinctly separate divisions the differential and integral calculus for the study of which a knowledge of analytic geometry is presupposed. Here analytics and the calculus are treated together and if the former is given less space than in the usual separate treatise, the student will be the gainer in acquiring a greater sum-total of applicable knowledge of that subject by the mode of treatment permitted by some knowledge of the calculus. The process of integration is discussed in an early chapter, a satisfactory sequence and decidedly useful to the student who may have occasion to apply the process before mastering the many ramifications of the differential. The chapter on the solution of equations which includes the use of determinants, and that on the conic sections with a discussion on the general equation of the second degree, the author believes by some readers may be regarded as unnecessary. Their inclusion is undoubtedly a wise addition; the majority of readers who are studying the subject or reviewing it are often only moderately proficient in the subject-matter of these chapters.

Besides the conventional topics of the differential and integral calculus, the work is well rounded-out for its intended purpose by the addition of chapters on the treatment of empirical data, complex quantities and periodic functions, and ordinary and partial differential equations. Especial mention may be made of the unusually full chapter on limits and continuity; fundamentals are carefully kept in mind in the demonstrations. Graphs for illustration and for analysis are fully employed and their use in dealing with the limiting values of functions in regard to whether the limit is approached from a less or greater value of the variable, is a striking example among others of the utility of the now well-appreciated custom of picturizing functions.

For its purpose a better choice and arrangement of topics would be difficult to find and their treatment is thorough and lucid. There is just one discordant note, an omission which many will expect to find in a work of this kind bearing this year's date. Modern technical writers use the vector method very freely and such terms as "rot," "div" and "grad" are meaningless, or indeed most of the transformations by this system, to readers who have not

specially studied the vector calculus. The book is, however, somewhat voluminous without this special method of analysis and for the customary mathematical methods employed in engineering practice, the reader will be fully satisfied with the ample collection of topics and the generous measure of their helpful explanation. The typographic work is of the highest character and especial mention may be made of the quality of the binding.

LUCIEN E. PICOLET.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 264, Differential Pressures on a Pitot-venturi and Pitot-static Nozzle over 360° Pitch and Yaw, by R. M. Bear. 9 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, five cents.

Measurements of the differential pressures on two Navy air-speed nozzles, consisting of a Zahm type pitot-venturi tube and an SQ-16 two-pronged pitot-static tube, in a tunnel air stream of fixed speed at various angles of pitch and yaw between 0° and ±180°, show for a range over −20° to +20° pitch and yaw, indicated air speeds varying very slightly over 2 per cent. for the Zahm type and a maximum of about 5 per cent. for the SQ-16 type from the calibrated speed at 0°.

For both types of air-speed nozzle the indicated air speed increases slightly as the tubes are pitched or yawed several degrees from their normal 0° attitude, attains a maximum around ±15° to 25°, declines rapidly therefrom as ±40° is passed, to zero in the vicinity of 70° to 100°, and thence fluctuates irregularly from thereabouts to ±180°. The complete variation in indicated air speed for the two tubes over 360° pitch and yaw is graphically portrayed in Figs. 9 and 10.

For the same air speed and 0° pitch and yaw the differential pressure of the Zahm type pitot-venturi nozzle is about seven times that of the SQ-16 type two-pronged pitot-static nozzle.

Report No. 266, Air Force and Moment for N-20 Wing with Certain Cut-outs, by R. H. Smith. 12 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, five cents.

The airplane designer often finds it necessary, in meeting the requirements of visibility, to remove area or to otherwise locally distort the plan or section of an airplane wing. This report contains the experimental results of tests on six 5 by 30-inch N-20 wing models, cut out or distorted in different ways, which were conducted in the 8 by 8-foot wind-tunnel of the Navy Aerodynamic Laboratory in Washington in 1924.

The measured and derived results are given without correction for Vl/v or for wall effect and for standard air density, $\rho = 0.00237$ slug per cubic foot.

PUBLICATIONS RECEIVED.

Isostacy, by William Bowie, Chief, Division of Geodesy, U. S. Coast and Geodetic Survey. 275 pages, illustrations, 8vo. New York, E. P. Dutton and Company, 1927. Price, $5.

Acetate Silk and Its Dyes, by Chas. E. Mullin, M.Sc., with a foreword by

Louis A. Olney, D.Sc. 473 pages, illustrations, 8vo. New York, D. Van Nostrand Company, 1927. Price, $6.

A Text-book of Inorganic Chemistry, edited by J. Newton Friend, D.Sc. Vol. vii, part 1, Oxygen, by J. Newton Friend and Douglas F. Twiss. 370 pages, illustrations, 8vo. Vol. ix, part 2, Iron and Its Compounds, by J. Newton Friend. 265 pages, illustrations, 8vo. London, Charles Griffin and Company, Limited; Philadelphia, J. B. Lippincott Company, 1921 and 1924.

Castles in the Ether, by John Wills Cloud. 189 pages, plates, 8vo. London, Simpkin, Marshall, Hamilton, Kent and Company, Ltd., 1927. Price, 21 shillings net.

The Architect in History, by Martin S. Briggs. 400 pages, plates, portraits, 12mo. Oxford, Clarendon Press; New York, Oxford University Press, 1927. Price, $3.75.

The Conquest of the Air. An historical survey by C. L. M. Brown, M.A. 126 pages, plates, portraits, 12mo. London and New York, Oxford University Press, 1927. Price, $1.

Aluminum Bronze Powder and Aluminum Paint, by Junius David Edwards. 104 pages, plates, 8vo. New York, The Chemical Catalog Company, Inc., 1927. Price, $3.

Phosphoric Acid, Phosphates and Phosphatic Fertilizers, by Wm. H. Waggaman assisted by Henry W. Easterwood. 370 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1927. Price, $7.50.

Photography: Its Principles and Applications, by Alfred Watkins. Third edition, revised. 336 pages, illustrations, colored plates, 12mo. New York, D. Van Nostrand Company, 1927. Price, $4.

Atomic Theory. An elementary exposition by Arthur Haas, Ph.D., translated by T. Verschoyle, Ph.D. 222 pages, illustrations, plates, 8vo. New York, D. Van Nostrand Company, Inc. Price, $3.50.

Dielectric Phenomena. Electrical Discharges in Gases, by S. Whitehead, B.A., edited with a preface by E. B. Wedmore. 176 pages, illustrations, 8vo. New York, D. Van Nostrand Company, Inc. Price, $4.

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Traité Scientifique et Industriel des Plantes Textiles. Felicien Michotte. Les Kapotiers et succédanés. Culture et Exploitation. 82 pages, illustrations, 8vo. Paris, Société de Propagande Coloniale, 1927. Price, 15 francs.

U S. Bureau of Standards. Safety Rules for the Installation and Maintenance of Electrical Supply and Communication Lines. Comprising part 2 of the fourth edition National Electrical Safety Code. 322 pages, illustrations, folded plate, 12mo. Price, sixty cents. Circular No. 332, Testing of Line Standards of Length. 22 pages, plate, 8vo. Price, ten cents. Scientific Papers No. 551, Absorption Spectra of Iron, Cobalt and Nickel, by W. F. Meggers and F. M. Walters, Jr. 22 pages, plate, 8vo. Price, ten cents. Washington, Government Printing Office, 1927.

U. S. Bureau of Mines. Bulletin 238, Subsidence Due to Coal Mining

in Illinois, by C. A. Herbert and J. J. Rutledge. 59 pages, illustrations, plates, folded diagrams, 8vo. Price, thirty cents. Bulletin 259, Placer-mining Methods and Costs in Alaska, by Norman L. Wimmler. 236 pages, illustrations, folded table, map, 8vo. Price, fifty-five cents. Technical Paper 378, Precipitation of Gold and Silver from Cyanide Solution on Charcoal, by John Gross and J. Walter Scott. 78 pages, illustrations, 8vo. Price, fifteen cents. Washington, Government Printing Office, 1927.

U. S. Department of Agriculture. Department Bulletin No. 1486, Highway Bridge Location, by C. B. McCullough. 32 pages, illustrations, plates, 8vo. Washington, Government Printing Office, 1927. Price, fifteen cents.

Reading with a Purpose. The Stars, by Harlow Shapley. 29 pages, 16mo. Chicago, American Library Association, 1927. Price, thirty-five cents.

National Advisory Committee for Aeronautics. Technical Notes, No. 257, Technical Preparation of the Airplane "Spirit of St. Louis," by Donald A. Hall. 12 pages, diagrams, photographs, quarto. No. 258, A Warning Concerning the Take-off with Heavy Load, by Elliott G. Reid and Thomas Carroll. 6 pages, 2 diagrams, quarto. Washington, Committee, 1927.

CURRENT TOPICS.

The Present State of Atomic Physics. A. SOMMERFELD. (*Physikal. Zeit.*, March 15, 1927.)—The introduction of the idea of quanta of energy has gone far toward destroying the rounded, unitary conceptions of physical action that were in vogue at the close of the last century. Bohr's conception of the atom came in and the discontinuous character of quantum relations were emphasized. The part played by whole numbers in the laws of nature came to be recognized as it had been long ago by the Pythagoreans when they studied the vibrations of strings.

In recent years the development has proceeded tempestuously. Heisenberg, in his quantum mechanics, has developed a logical method. This method is as successful in its applications as remarkable in its premises. Heisenberg goes on the principle, based on the theory of cognition, that physical description of phenomena should employ only observable elements. In the case of atoms these are the frequency and intensity of their spectral lines. "In the transition from one atomic state to another, the chance location of the electron on its path and the duration of its revolution cannot be observed and hence disappear from the theory." The results of quantum mechanics in the hands of Heisenberg, Born-Jordan, Dirac and Pauli have everywhere approved themselves, but the manipulation is very troublesome and abstract to a repellant degree. Hereupon Schroedinger comes to our help. His point of departure is the opposite to that of Heisenberg, but his results are the same apart from their expression and bearing. This agreement guarantees in accordance with experience the truth contained in Schroedinger's method. He would like to construct a theory of a continuum that clings as closely as possible to the mathematical methods of the wave theory. In opposition to Heisenberg's method the magnitudes denoting state in Schroedinger's theory are not individually subject to experimental verification. While Heisenberg carefully holds to experimental magnitudes, Schroedinger, and to an even greater extent his predecessor de Broglie, advances daringly beyond experience and forms wave images that lie behind experience and are therefore metaphysical. In any case the progress won in the mathematical treatment of quantum problems is immeasurable.

Sommerfeld raises the question of the bearing of these new theories on the Bohr atom with its nucleus and planetary electrons. "Is its reality threatened by the new developments? I think not. As long as there is a chemistry with a periodic system of the elements there will be a step-by-step construction of atoms from electrons."

"One hears occasionally the following parallel between Maxwell's

theory and that of Bohr. Forty years ago, when I was a student, the question was, 'What is the essential feature of Maxwell's theory, the equations or the mechanical model by which Maxwell strove to support his theory?' Hertz, as is well known, answered the interrogation in one way, in favor of the equations, while Boltzmann, on the other hand, was for the model. In an article published in my youth in the *Annalen der Physik*, I endeavored to round out a gyroscopic model of the ether, proposed by Kelvin, but I soon went over to Hertz's point of view, just as the general progress of physics has relegated ether models to the shelf. Will the same thing occur to the atomic models of to-day? Will they be replaced, perhaps, by Schroedinger's wave equation or by the corresponding matrix algebra of Heisenberg? By no means! For Bohr's model of the atom enters as a unifying constituent into Schroedinger's equation as well as into Heisenberg's addition to the Hamiltonian function. The number of electrons in the atomic model determines the number of independent variables in the former equation, while the potential energy between electrons and nucleus makes its appearance explicitly in the work of both Schroedinger and Heisenberg. Hence, without an atomic model there is no wave equation and no matrix calculus. The new developments neither can nor will displace the models of atoms, but they do furnish the long-sought micro-mechanics, adequate for the physics of the atom. On the other hand, the old ether models were only externally attached to Maxwell's equations. In these equations there is nothing of the tops, flywheels and cells of the ether models. These offshoots along with the rigid, material ether could be excised without injuring Maxwell's equations. However, if one should cut away the atomic model from Schroedinger's wave equation, for example, there would be nothing left." It must not be thought that the atomic models remain quite unscathed by the march of mathematical treatment. Heisenberg does not regard the electron as definitely localized and Schroedinger presents a picture of this when he spreads the charge of the electron out into a continuous space charge. "I," says Sommerfeld, "do not quite believe in these daubed, dissolving electrons, just because, outside of the atom, corpuscular concentrated electrons with high velocity have been certainly demonstrated by experiment. It is true, nevertheless, that Schroedinger's continuous density has rendered priceless service in the calculation of the physical and chemical effects of atoms, and in this sense is real in a higher degree than the electron of the old theory localized in a point. Not only the spatial relations within the atomic model must be modified but the temporal ones as well." Also the elementary representation of revolution in time within the model of the atom cannot be maintained in accord with the new theory. The fine comprehensibility of the microcosmic system of planets is lost beyond recall, if the present position of the quantum theory remains unchanged.

G. F. S.

The Present State of Atomic Physics. O. W. RICHARDSON. (*Proc. Phys. Soc.*, London, **39**, April 15, 1927.)—The combined effect of the discovery of the electron, of Bohr's conception of the atom, and of Planck's quantum theory, has been that "they have turned spectroscopy from a heterogeneous collection of miscellaneous facts into a rapidly advancing science, and have created several other new branches of science of varying degrees of importance. Whilst these ideas suitably grafted on to the general body of earlier physical doctrine have been able to coördinate vast stores of existing facts and to predict, perhaps, even vaster stores of new ones, they do not appear to be sufficiently wide in scope to embrace all that is required in atomic physics. There are certain groups of phenomena or facts which do not fall into the general framework which I have indicated, or, if they are forced in, the result is found to be a misfit." Here are some of these recalcitrant groups.

(1) The wave theory of light has not yet been reconciled with the quantum theory. "The same light behaves as a wave when it is travelling through a telescope and is occupied with refraction or dispersion, and as a projectile when it is engaged in emission, absorption or photo-electric action. The energy of the radiation behaves as though it possessed at the same time the opposite properties of extension and localization."

(2) "The remarkable fact that the mean free path of an electron in the inert gases, and especially in argon, becomes exceedingly long when the velocity of the electron is reduced. This phenomenon seems incomprehensible on the Rutherford-Bohr picture of the atom." There are additional contradictions of a more recondite nature—the insufficiency of integral numbers in spectroscopic theory; the discrepancy between the Landé splitting factor, operative in the Zeeman effect, derived from experiment and that obtained from theory; the difficulty of reconciling the interpenetration of the electron orbits of a complicated atom with the maintenance of their identity and stability; the existence of the magnetic anomalies, both spectroscopic and gyromagnetic; certain difficulties in reconciling the excitation of soft X-rays with the Bohr scheme of levels; and the remarkable angular distribution of medium speed electrons upon reflection from some solids.

"Whilst the foregoing difficulties are by no means all of equal weight, and many of them if standing alone might be treated, perhaps, with indifference, yet taken together they form a solid obstacle. It is the consideration of such questions as these which in the last year or two has led atomic physicists to look for some radical departure from the points of view hitherto used by Bohr, Sommerfeld and their followers. The revolt, in fact, seems to have been started by Bohr himself." The body of classical physical theory with its prestige of age and achievement is valid for phenomena on a large scale where frequencies are low. Atomic physics is governed by the empirically found quantum theory with its high

frequencies. Bohr advanced the Correspondence Principle to bridge the gap between the two theories. Then in 1925 Heisenberg extended the principle by indicating an intimate analogy between classical dynamics and a phase of quantum dynamics. Employing the quantities really known for atoms, viz., the intensity and frequency of the radiation they admit and absorb, and eschewing the location and time of revolution of electrons in the atom as unknown in fact, he showed how to take a problem stated in the mathematical language of classical dynamics and from it to reach a solution of the corresponding problem of quantum dynamics by translating the original quantities according to a certain method and by applying to the new kind of quantities appropriate operations. "The quantities which operate in this new quantum dynamics are not ordinary numbers, and the operations to which they conform do not agree in form with the laws of algebra. It was pointed out by Born and Jordan that the laws which govern them are the same as those which govern the operations in the theory of matrices." This matrix theory is one of discontinuity.

A second competing theory is based on continuity. It assumes that all mechanics, classical as well as quantum, "is ultimately dependent on a wave-motion, and, in fact, that the solution of a mechanical problem is the solution of the partial differential equations of an appropriate wave-motion. It is a most remarkable thing that the results of the two theories are mathematically identical." Professor Richardson by applying Hamiltonian theory to the statement of Fermat's Principle of Least Time derives this: "The motion of a particle in a field of force can be represented as a ray of a propagated wave surface. All classical dynamics is built up out of the motion of particles, and can therefore be equally well regarded as wave-motions with the energy travelling along certain rays, the paths of the particles." L. de Broglie has recently developed such a wave theory of electrons in which the electron is looked upon as a train of waves. He finds confirmation for the identification of the electron with a wave-motion in this, that "as the corpuscular theory of light breaks down when the obstacles and apertures become comparable with the wave-length, so the particle theory of dynamics breaks down when the distances concerned are of atomic dimensions. And the reason is the same in both cases, namely, that both are wave phenomena, and in each case the dimensions concerned become comparable with the wave-length." Then followed Schroedinger with his brilliant development of wave mechanics. His theory permits the atom to retain its local importance. "Although the theory presupposes the vibration phenomenon to extend from the centre of the atom to infinity, it is for all practical purposes confined within a region which we are accustomed to regard as of atomic magnitude. This is something like the theory of the electromagnetic mass of an electron which distributes the mass all over the universe except inside the electron in theory; but it nevertheless locates it at the

electron for all practical purposes." This new theory of wave mechanics has already made notable achievements. It removes some of the discrepancies listed by Richardson and reduces the importance of others. The author alleges against it that "in its present form it appears to offer no explanation of the atomicity of matter and electricity."

In some of the modern phases of physical theory there are contained surprising metaphysical and philosophical implications. In a recent article Sommerfeld raises the question as to whether the commonly accepted relation between cause and effect can be defended. There are quantities, such as amplitudes in Heisenberg's theory, which depend in precisely similar ways upon the end as well as on the beginning of processes. Richardson further says, "It may be pointed out that some of the suggestions which have been made would introduce a new principle (or lack of principle) into physics by violating human free will. To account for the photo-electric effect, for example, it has been suggested that the emission of a quantum of radiation by the atom A and its subsequent absorption by an atom B involves a collusion between the atoms A and B of such a nature that the emission from (absorption by?) B is predetermined by the event of ejection from A. Now suppose A is an atom on a star which the light left years ago, and B is an atom on the photographic plate of a telescope set up to photograph the star. It is obvious that there are a large number of things which I might do which would prevent that predetermination from being carried out. It is, of course, an indication of the seriousness with which the difficulties have been felt that such views should have received consideration." G. F. S.

Solid Helium. W. H. KEESOM. (Communications, Physical Lab. University, Leiden, No. 184.)—In July, 1926, preliminary notices of the solidification of helium were published in *Nature* and in *Comptes Rendus*. His successor had succeeded where Kamerlingh Onnes with his long experience with gases at low temperatures had failed. On the very day when the latter first liquefied helium he tried to convert it into a solid by using a vapor pressure of less than 1 cm., but no solid appeared. Again and again he returned to the attempt but always without success. In 1919 he failed once more though he used a pressure of less than 1/50 mm., at which the temperature was estimated to be no more than .82° K. This negative result made him wonder whether helium might, perhaps, remain liquid even at the absolute zero. Meanwhile certain results obtained in the study of changes in the melting-point of solid hydrogen produced by pressure had caused Keesom to reflect whether the right way to solidify helium might not be by the application of pressure. An apparatus, necessarily elaborate, was constructed in which the solidification of helium, if it occurred at all, would take place in a capillary tube surrounded by liquid helium.

It was arranged that the vapor pressure of this liquid bath and the pressure exerted on the liquid helium to be solidified could be varied independently. Furthermore, a closing of the capillary, such as would result from the formation therein of solid helium, would produce the rise of a mercury column in a tube along the axis of which was stretched a thin platinum wire forming one of the branches of a Wheatstone Bridge. The rise of the mercury changed the resistance of the branch and made a galvanometer needle deflect. In the first experiment, June 25, 1926, the pressure of the bath was reduced by a pump to about ½ mm. mercury and the pressure on the liquid helium in the capillary was made 250 kg./cm.². With the proper arrangement of stopcocks the galvanometer showed a deflection and it was concluded that the helium had solidified and blocked the capillary tube. "The temperature of the bath was now raised till the pressure was 1 atm. The capillary remained blocked. The pressure in the capillary was lowered. At 150 kg./cm.² the capillary was still blocked. At 100 kg./cm.² blocking had disappeared. At 130 kg./cm.² the capillary was blocked again, as also at 128. At 125 kg./cm.² it was open, and at 126 kg./cm.² also. Inference: At 126 kg./cm.² helium is liquid, at 128 kg./cm.² it is solid." Further observations were taken with lower pressures, and consequently lower temperatures, of the helium bath. Each decrease in the bath temperature was followed by a reduction of the melting pressure of the solid helium in the capillary. For example, with 50 mm. of mercury as pressure on the bath, the corresponding temperature being 2.40° K., the solid melted at 48 kg./cm.². Enough experiments were repeated to show that the results were reproducible.

Subsequent experiments extended the pressure on the bath to as low as .057 cm., temperature 1.19° K., where the melting pressure was 25.3 atm. When the melting pressures are plotted as ordinates against temperatures as abscissas its shape indicates that "it will never be possible to solidify helium, liquid under its own saturation pressure, by lowering the pressure alone. So the surmise expressed by Kamerlingh Onnes that helium (under its own saturation pressure) remains liquid down to the absolute zero (perhaps gradually changing into the vitreous amorphous state), would be established." It would appear that, below the liquid-gas critical temperature, the solid and the gas cannot exist in contact and, further, that solid helium does not turn directly into vapor, as ice does, but must melt before evaporating.

Professor Keesom quite naturally desired to see solid helium and to this end replaced the capillary tube, which was opaque, being of metal, by a glass tube containing an iron stirring rod operated by an electromagnet. Helium was compressed into this tube, the surrounding bath being at 13.3 mm. mercury and 1.9° K. The stirrer was kept moving up and down while the pressure on the liquid in the tube was increased. "At a certain pressure the stirrer stuck; the helium had become solid. There was, however, nothing peculiar

to be seen in the tube. Solid helium is perfectly transparent." After other experiments it is said, "Again there is nothing peculiar to be seen in the helium; no surface of demarcation between solid and liquid, nor between solid and gas or between liquid and gas. There was no indication of difference in refraction, nor change of volume. Helium solidifies to a homogeneous transparent mass. That it is a crystalline mass, seems to follow from the fact that the melting curve is sharply defined." In one case there was a solid block of helium 15 to 20 mm. long that was moved along the containing tube through a distance of some millimetres. Its motion was observable only by its effect on black particles in the liquid.

G. F. S.

Effect of Chemical Combination on X-ray Absorption. W. B. MOREHOUSE. (*Phys. Rev.*, June, 1927.)—Following Benoist, writers on X-rays have been accustomed to state that the absorption coefficient of an element for these rays is independent of its state of combination, that is, it is the same whether the element be free or combined chemically with other elements. In recent years doubt has arisen as to the accuracy of this statement. In this series of experiments the absorption of several pairs of aqueous solutions was measured both before and after chemical reaction. A cell with two compartments, each holding a solution, was interposed in the path of the X-ray beam. The solutions were mingled and after completed chemical combination the effect on the beam was again determined by a differential method. The source of X-rays was a water-cooled molybdenum Coolidge tube, both the direct rays and those filtered through zirconium being used. Corrections were applied for change of density due to combination. In what follows the substances in brackets were in one compartment of the cell while those in parentheses occupied the other compartment.

(*A*) $[KI + I_2] + (2Na_2S_2O_3) \longrightarrow KI + 2NaI + Na_2S_4O_6$.

(*B*) $[K_2Cr_2O_7 + 6KI] + (6KI + 14HCl) \longrightarrow 8KCl + 2CrCl_3 + 3I_2 + 6KI + 7H_2O$.

(*C*) $[NaOH] + (HCl) \longrightarrow NaCl + H_2O$.

(*D*) $[KOH] + (HCl) \longrightarrow KCl + H_2O$.

(*E*) $[I_2$ in 70 per cent. alcohol$] + (2Na_2S_2O_3) \longrightarrow 2NaI + Na_2S_4O_6$.

"Reaction (*A*): The mass absorption coefficient for the solution after reaction for direct beam approximately 0.24 per cent. less than before reaction; for filtered beam 0.36 per cent. less. Reaction (*B*): Direct beam, 0.25 per cent. greater. Reaction (*C*): Direct beam, no appreciable change. Reaction (*D*): Direct and filtered, no appreciable change. Reaction (*E*): Direct beam, 0.36 per cent. less." In the two reactions (*C*) and (*D*) the valence of all elements is unchanged by the reaction and the absorption coefficient is likewise unchanged. "In reactions (*A*) and (*E*) the iodine changes its

valence from 0 to −1 and the valence of sulphur increases positively. In reaction (*B*) the iodine changes its valence from −1 to 0 and chromium from 6 to 3. The results indicate that the mass absorption coefficient for an element depends upon its valence or state of chemical combination." It seems likely that the absorption of iodine in the free state exceeds its absorption when in combination.

G. F. S.

Examination of the Radio-activity of Matter Exposed for Long Periods to Solar Radiation. MISS ST. MARACINEANU. (*Comptes Rendus,* June 20, 1927.)—On May 30 the authoress reported to the Academy the results of her examination of lead used as roofing material and therefore exposed to sunshine. The electrometer was placed on the horizontal roof, which caused the instrument to deflect and thus indicate a marked degree of radio-activity. On the advice of the astronomer Deslandres she has continued her investigation.

To any claim that the lead had become possessed of radio-active properties in consequence of its exposure to solar radiation, it might be objected that the metal might have been radio-active to begin with. To test this possibility a piece of lead was removed from the roof and examined in the laboratory. No radio-activity was detected on the under face that had not been insulated, while the upper face presented at first a value as large as that obtained when the electrometer was used on the roof but growing less day after day.

A further objection might be urged that the effect discovered was due to the accumulation of radio-active material on the roof. Such material should be deposited on exposed surfaces other than the lead. The electrometer was put on a horizontal stone surface close to the lead roof, but in that position no radio-activity was found. In addition two test pieces of lead were taken from the cornice of the Paris Observatory, one from the southern and the other from the northern face of the building. The specimen from the south side showed much more radio-activity than the other, requiring only a little more than half as long a time to produce a given motion of the needle of the instrument as was needed by the other piece.

Fortunately the Observatory has copper and zinc as roofing materials as well as lead. Test pieces of zinc and of copper taken from places exposed to the sun both displayed radio-activity, though to a smaller degree than lead. A piece of zinc from a northern exposure was slightly radio-active. Additional studies were made of iron, cast iron and stone, both porous and compact, but either no radio-activity or at most merely a trace was detected.

In a remark on the communication just discussed, Deslandres directs attention to the failure of variations of pressure and temperature to affect radio-active action. The radiation of the sun

emanation from pressures and temperatures surpassing those procurable on the earth may accomplish effects in radio-active transformations impossible to terrestrial agencies. He suggests further that the radio-activity of metal exposed to the diffuse light of the sky may need for explanation recourse to the penetrating radiation of Kohlhörster and Millikan. G. F. S.

Newton's Mechanics and Its Influence on the Formation of Modern Physics. ALBERT EINSTEIN. (*Naturwissenschaften*, March 25, 1927.)—"It was Newton's goal to answer the question, 'Is there a simple rule by which to calculate the motions of the heavenly bodies of our solar system, provided the state of motion of all these bodies is known at one instant of time?'" Kepler had formulated his three empirical rules relating to the motions of these bodies. Galileo had made a significant beginning in the development of the laws of motion. What Kepler and Galileo had done helped to present a broad view of motion, but did not show how motion changes from moment to moment. To penetrate into the details of motion Newton brought over into dynamics the conception of force already well established in statics and introduced the idea of mass, while for the mathematical method he devised differential and integral calculus. The significance of his accomplishment was by no means limited to the solution of mechanical problems. Down to the end of the nineteenth century men sought to find an explanation of all physical phenomena in masses that acted in accordance with Newton's laws of motion. On such masses, though of minute size, were based the kinetic theories of heat and of gases. Magnetism and electricity were stated in forms analogous to the law of attraction between masses. Even after Faraday and Maxwell had presented their theory of optics and electrodynamics, the first great fundamental advance in physics since Newton, Kelvin, Boltzmann and Maxwell went to much trouble to explain the new type of field in terms of distributed material particles. Just because of the fruitlessness of such endeavors there has come in the present century a revolution in basic conceptions, and theoretical physics has at last departed from the direction which Newton gave to it two centuries ago.

Newton knew the vulnerable points of the structure which he erected better than some of those who came after him. Einstein says, "This circumstance has always aroused my respectful admiration." The following are now seen to be weak features in his system:

(*a*) The ideas of absolute time and of absolute space.

(*b*) Forces acting at a distance and instantaneously. Newton himself recognized that his law of gravitation could be no final expression but was merely an empirical rule derived from experience.

(*c*) The setting up of mass to be the determining circumstance for both weight and inertia.

After the belief in the electromagnetic field had firmly established itself, the special theory of relativity came and destroyed the conception of absolute simultaneity. This carried with it the denial of such forces as act instantaneously. Mass was recognized as no longer invariable but dependent on energy content and Newton's laws of motion were seen to be true only for small velocities. They were replaced by relations in which the velocity of light in a vacuum played the leading rôle as the highest possible velocity.

Then came the general theory of relativity with its reduction of inertia and gravitation to characteristics of a field. Time and space were divested of much of their former values. It may well be that even the law of casuality may have to be discarded. G. F. S.

Timber an Important Check on Run-off of Rainfall on Hilly Farm Lands. (U. S. Department of Agriculture Press Service.)—That a relatively small amount of timber has a decided influence in reducing the rate of run-off of rainfall from watersheds on small agricultural areas, is shown by a study just completed on a 112-acre farm in Madison County, Tenn.

This study was characterized by E. N. Munns, in charge of the Office of Forest Experiment Stations of the Forest Service, as one of the most important contributions toward our knowledge of the effect of forests upon water flow that has been made in recent years. It is an indication, he said, of the valuable part that farm forestry can play in a program for controlling erosion and the diminution of floods in the Mississippi Valley.

Observations were made over a period of several months on two small watersheds on this farm, one of which was 14 per cent. in timber and the other approximately 39 per cent. It was found that the average run-off of surface water during periods of heaviest rains was some 50 per cent. greater on the watershed with the least timber, although the interception and absorption of rainfall on timbered areas is much greater at the beginning of a rain than later when the ground becomes saturated and, therefore, the effect of timber in reducing run-off is slight when the maximum rate of run-off occurs after considerable rain already has fallen on the watershed.

The site chosen for this study, which was made by C. E. Ramser, Drainage Engineer of the Bureau of Public Roads of the Department of Agriculture, was quite hilly, and typical of the hill lands under cultivation in that region. The cleared lands have been devoted to the cultivation of cotton for many years, with very little or no protection against erosion. As a result most of the top soil on the steeper slopes has been washed away by heavy rains and deposited over the bottom areas or carried off the watershed. The subsoil over the steeper slopes is exposed in many places and does not possess the fertility necessary to produce a profitable cultivated crop.

Such lands as these, which can be found on many hilly farms

throughout the country, according to Mr. Munns, are well suited for use as farm woodlands, and by establishing and protecting a growth of timber on them, they not only will produce a profitable crop of wood, but the timber will protect the slopes from erosion, and so contribute in some measure toward flood prevention.

Fluogermanates of the Univalent Metals.—Winkler, the discoverer of germanium, described potassium fluogermanate; this has been the only known fluogermanate. JOHN HUGHES MÜLLER, of the University of Pennsylvania (*Proc. Am. Philosophical Soc.*, 1926, **65**, Supplement, 44–57), has extended his series of researches on germanium to include the preparation and study of the following fluogermanates: Lithium, sodium, potassium, rubidium, cæsium, silver, thallous. These salts are formed by union of two molescules of the fluoride of the univalent metal and one molecule of germanium fluoride; they have the general formula R_2GeF_6, in which R represents a univalent metal. The fluogermanatic acid radical is quite stable, for aqueous solutions of the fluogermanates do not yield a precipitate of germanium sulphide on saturation with hydrogen sulphide either in neutral solution or in the presence of free hydrochloric acid. Dry lithium fluogermanate volatilizes rapidly without melting at 400° C. Dry silver fluogermanate melts at 80° C., and slowly darkens and decomposes at temperatures above 100° C.

J. S. H.

Large Springs in the United States.—OSCAR EDWARD MEINZER (*U. S. Geol. Survey Water Supply Paper 557*, 1–94, 1927) has written a monograph on the large springs of the United States. The monograph is devoted chiefly to springs of the first magnitude, *i.e.*, those with an average discharge of 100 or more cubic feet of water per second. At least 65 such springs occur in the United States; and several of them have an average yield of 500 or more cubic feet of water per second. The large springs usually occur in limestone or in extensive volcanic rocks chiefly jointed basalt, also in obsidian, rhyolite, and fragmental volcanic material; they usually issue in canyons or valleys which extend down into the water-bearing strata or on lowlands at the base of escarpments formed in part by these strata. Faults may provide large openings for the escape of the water. The discharge of large springs fluctuates according to the precipitation, atmospheric temperature, and other weather conditions; fluctuations are usually more sudden and more marked in limestone springs than in volcanic rock springs. As a rule, the water of large springs is not highly mineralized; it is meteoric water which has not reached depths of more than a few hundred feet below the surface; and its temperature is not far from the mean atmospheric temperature of the region. The rocks, in which the large springs occur, range in geological age from early paleozoic to quaternary. Springs of considerable magnitude occur in at least seventeen states.

J. S. H.

Water and Metal Pipes.—H. W. CLARK, of the Massachusetts Department of Public Health (*Jour. New England Water Works Asso.*, 1927, **41**, 31–44), has studied the action of water and metal pipes upon each other. The amount of metal, which passes into solution in the water within the pipe, varies under different conditions, with different waters, and with the metal composing the pipe. Iron is more readily dissolved than any other metal. With galvanized pipe, solution of the iron is markedly retarded but zinc is continually dissolved as long as the galvanizing lasts. When pipes are lined with tin, they are difficult to handle from a plumbing viewpoint; however, but little of the tin passes into solution in any type of water. Copper pipes yield minute amounts of copper to the water. Brass pipes likewise yield minute amounts of copper and, in addition, zinc in more appreciable amounts. The suggestion is made that every house piping system be well flushed out each morning in order to remove the water which has stood in the pipes over night. Both surface waters and ground waters have a hydrogen-ion concentration on the acid side of true neutrality. When such water remains in a pipe of brass or copper for several hours, the dissolved oxygen, carbon dioxide, and hydrogen-ion concentration decrease as corrosion occurs. J. S. H.

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